HOW IT WORKS

TESLA TRUCK
REVEALED: ELON MUSK'S GREEN GIANT

MAKE EDIBLE WATER BALLS

HOW IT WORKS

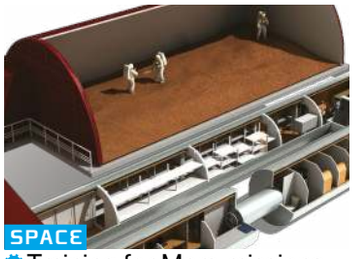
THE MAGAZINE THAT FEEDS MINDS

DISCOVER

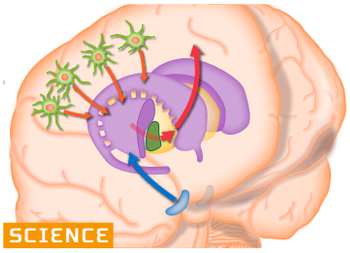
SCIENCE
THE PHYSICS OF EXTREME SPORTS

AMAZING CUTAWAYS

ENVIRONMENT
Meet the world's biggest bird



SPACE
Training for Mars missions



SCIENCE
How your brain senses time

+ AMAZING TECH E-BOOK
EXCLUSIVE CODE FOR EVERY READER

TECHNOLOGY
FLOATING CITIES OF THE FUTURE

SUPERSONIC STEALTH JETS

THE ADVANCED ENGINEERING & TACTICAL TECH POWERING THE WORLD'S GREATEST FIGHTERS

+ PAPER ROCKETS EXCLUSIVE OFFER

+ LEARN ABOUT

TECHNOLOGY PAPER MILLS **DEFRAGGING** OIL PUMPJACKS
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WW1 POST SPACE **ASTEROIDS** COLD DUST **ALPHA CENTAURI**
ENVIRONMENT SNAIL SHELLS **METAMORPHOSIS** HIMALAYAS

FUTURE
ISSUE 110

TWO GREAT SHOWS TOURING THE COUNTRY!

'IT'S SO MUCH BETTER THAN THE BOOK!' DAVID WALLIAMS

David Walliams
GANGSTA GRANNY

★★★★

'TOTALLY GRANTASTIC!'
MAIL ON SUNDAY

David Walliams
AWFUL AUNTIE

LIVE ON STAGE!

★★★★

'ANOTHER HUGE DRAMATIC HIT!'
WHAT'S ON LIVE

See birminghamstage.com for tour dates!

ISSUE 110

WELCOME

The magazine that feeds minds!

Anyone who has seen *Top Gun* has felt the need...the need for speed! Or at least they've imagined what it's really like to take control of a superfast, super-agile fighter jet. These powerful planes represent the pinnacle of aviation and stealth technologies, but – even with the increased reliance on autonomous technologies – their real value lies in the intuition, experience and bravery of the men and women who pilot them. Flying at supersonic speeds or performing aerial manoeuvres puts huge stresses on the body, and split-second decisions can be the difference between life and death.

Speaking of death-defying feats, if the awesome events of the Winter Olympics have inspired you then check out the science of snowboarding and other extreme sports on page 52. Enjoy the issue!

Jackie **Jackie Snowden**
Editor

"The idea sounds as if it's been taken out of a movie, but ocean settlements may soon become a reality"
Floating Cities, page 26

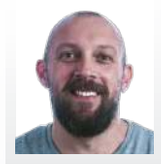
Meet the team...

Charlie G
Production Editor
Imagine waking up every morning on a floating city in the middle of the ocean, a roaming world filled with technological wonders. I mean, water way to live!

Baljeet
Research Editor
With over 50 billion plastic bottles made in the US alone each year, it's no surprise we are facing a plastic crisis. Could edible water bottles be the solution?

Charlie E
Staff Writer
I've always wondered why some motorways seem to roar under my cars tyres while some seem to be so quiet. Find out why some roads are noisier than others on page 20.

Scott
Staff Writer
It's amazing how animals living in the Himalayas survive the mountain range's challenging and unpredictable conditions. Discover how on page 72.



Duncan
Senior Art Editor
I'm old enough to remember when the blockbuster *Top Gun* was released in 1986, so I was interested to read about the latest fighter jets taking to the skies on page 12.

Laurie
Studio Designer
Isn't mother nature amazing? This month I marvelled at the incredible transformations that animals undergo during metamorphosis. Learn more on page 64.

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+ PULL-OUT POSTER
Moons of the Solar System
PAGES 50–51

MEET THE EXPERTS...

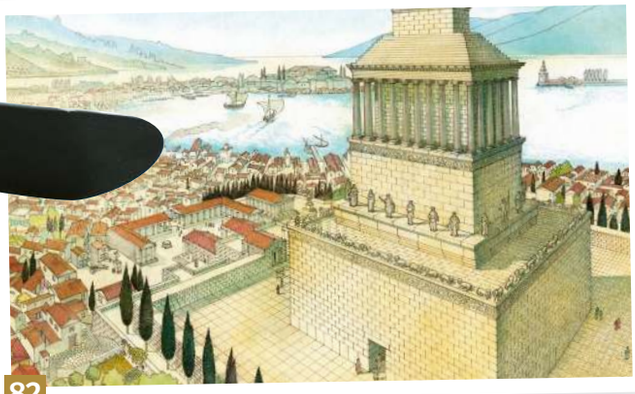
Laura Mears
In this issue's science section, Laura explains the forces behind incredible, death-defying stunts and why adrenaline junkies can't get enough of that extreme-sports rush!

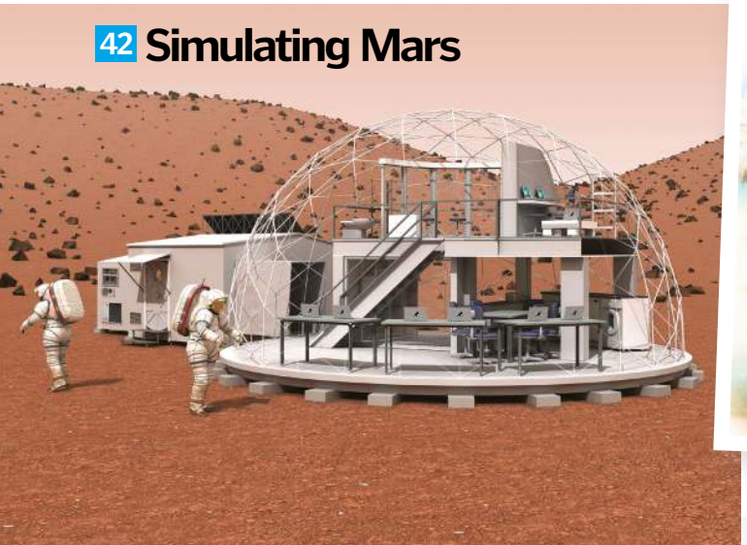
Jonny O'Callaghan
This month, Jonny reveals how future astronauts are preparing for Mars. He also takes us inside some of the world's greatest fighter jets.

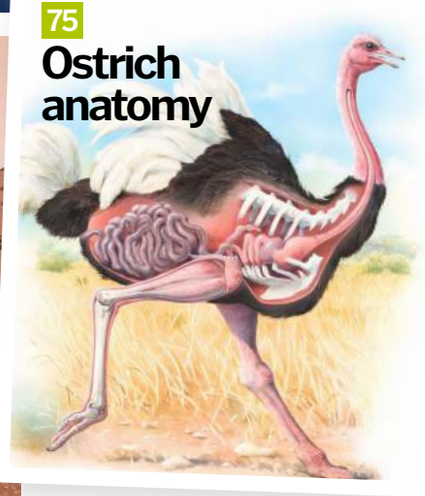
Steve Ashby
In our tech teardown, Steve opens up Apple's state-of-the-art iMac Pro. It's the company's fastest and most powerful computer ever. Find out how it works on page 36.

Tim Williamson
Messages from home are incredibly important for soldiers' morale during wartime. On page 81, Tim explains how British post was delivered to and from the front line during World War I.

Jodie Tyley
Over in the history section, Jodie opens the doors to the glorious Crystal Palace and takes us on a tour of the Great Exhibition of 1851 – a landmark event showcasing industries from all over the world.







REGULARS

GLOBAL EYE

Showcasing the incredible world we live in

The lizards' glowing skeletons were revealed under UV light

Chameleon bones glow in UV light

Rare biogenic florescence has been detected in these luminous lizards for the first time

Researchers in Munich have recently discovered that different species of the genus Calumma biogenically fluoresce. Their bones glow in the dark under UV light, so brightly in fact that they become visible through the skin. This ability is often seen among marine species, but biogenic fluorescence is rare in land animals. David Prötzel, lead author and PhD student at the Bavarian State Collection of Zoology (ZSM), explained in a statement: "We could hardly believe our eyes when we illuminated the chameleons in our collection with a UV lamp, and almost all species showed blue, previously invisible patterns on the head, some even over the whole body."

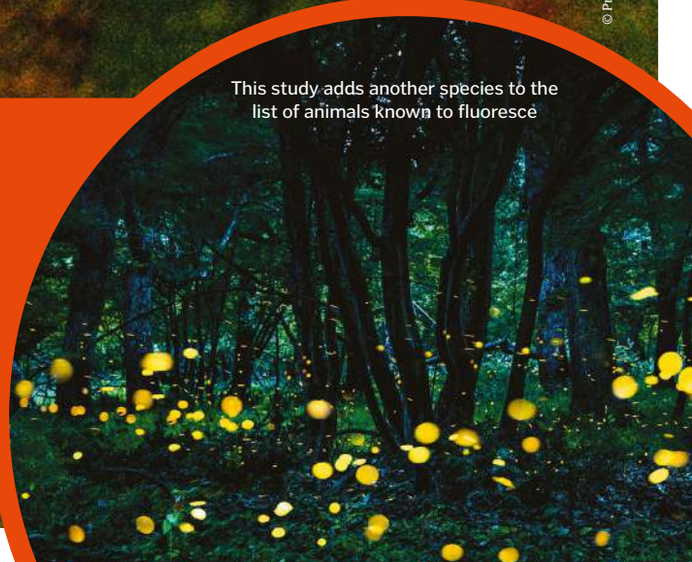
Though bone tissue is naturally fluorescent (partly due to its collagen protein) few land-dwelling species show their inner glowing ability on the surface. This study used micro-CT scans to reveal that patterns of blue fluorescence matched a pattern of small bony projections called tubercles beneath the skin on the chameleons' skulls. The skin covering these tubercles was found to be very thin, consisting of a transparent layer of epidermis, therefore allowing UV light to reach and be absorbed by the bone beneath.

The study also found that the male chameleons had significantly more fluorescent tubercles than females. Researchers suggest this could help chameleons recognise other members of the same species. However, further investigations are required to explain the biological relevance of this ability.

The way things glow

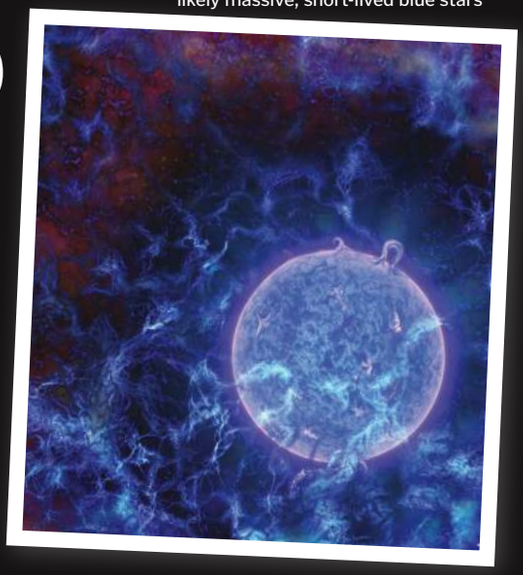
Biogenic fluorescent tissue, such as bones and teeth, contains a protein that glows when hit with ultraviolet light. However, rather than just happening to reflect light, some animals actually produce and emit light of their own. These luminous animals use light-emitting molecules (luciferin) and enzymes (luciferase), which undergo a chemical reaction that emits photons.

Fluorescing species use their abilities to camouflage themselves, lure prey towards them or communicate with other members of their species. One of the most well-known creatures that bioluminesce are fireflies, which flash brightly from their lower abdomens to attract a mate and to avoid predators. Some species of worms and beetles are also known to glow in the dark.



This study adds another species to the list of animals known to fluoresce

Artist's concept: the earliest suns were most likely massive, short-lived blue stars



WE MAY HAVE FOUND THE UNIVERSE'S FIRST STARS

These ancient suns formed just 180 million years after the Big Bang

Astronomers have detected signals from the first stars that formed after the universe began. As part of the Experiment to Detect the Global Epoch of Reionization (EDGES), the team used an antenna to detect radio signals from the early universe. "Telescopes cannot see far enough to directly image such ancient stars, but we've seen when they turned on in radio waves arriving from space," explained lead investigator Judd Bowman of Arizona State University, US.

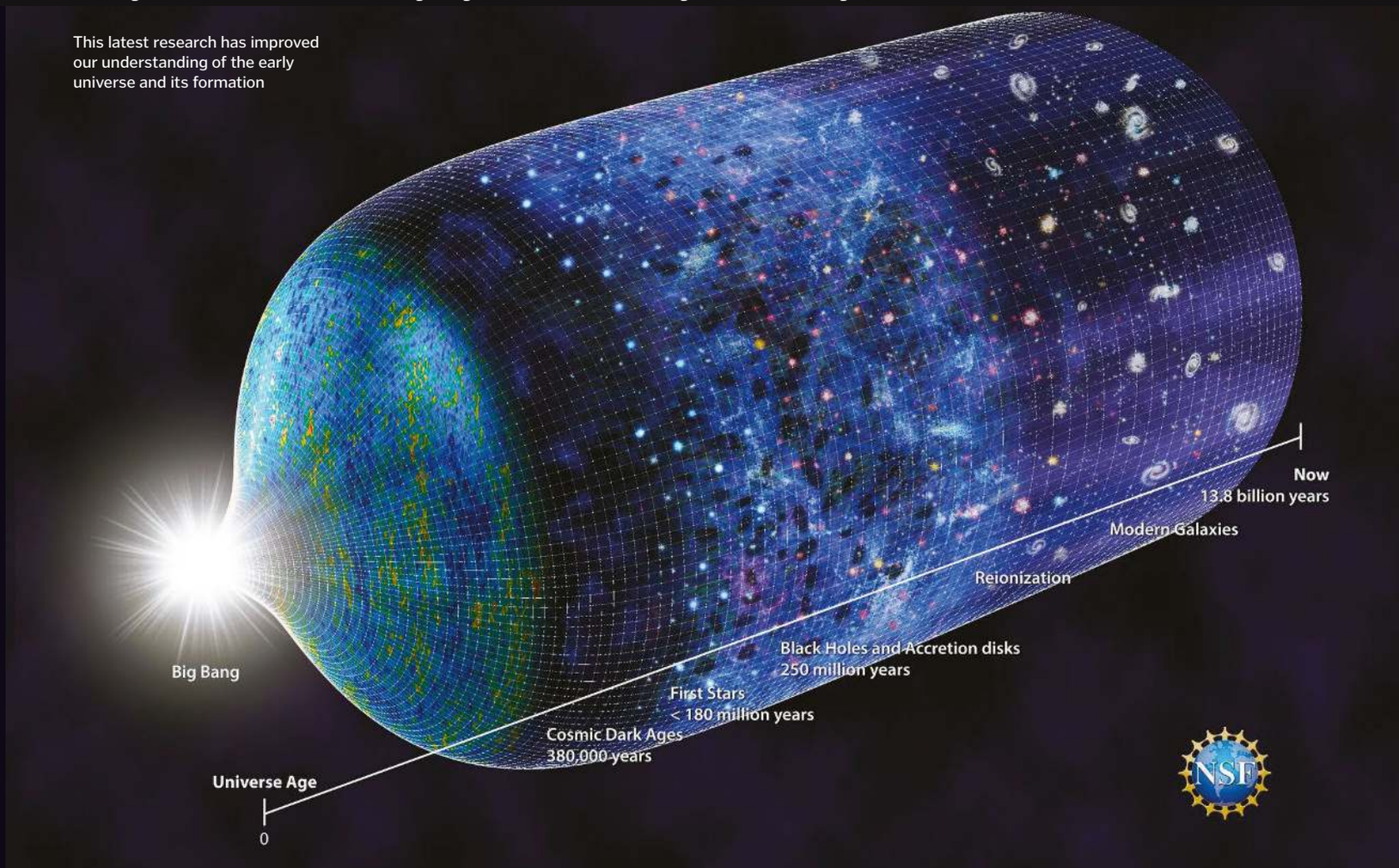
To detect these first twinkles astronomers look for indirect evidence in the form of changes in the cosmic microwave background (CMB), which is the radiation that permeates the universe and is thought to be the remnants from the Big Bang 13.8 billion years ago. Detecting the small changes that astronomers expect from these stars is a huge challenge due to Earth's radio-wave-filled environment.

"Sources of noise can be 10,000-times brighter than the signal – it's like being in the middle of a hurricane and trying to hear the flap of a hummingbird's wing," explained Peter Kurczynski, the National Science Foundation programme director who oversaw funding for EDGES.

Despite the challenges the astronomers managed to pick up the signal thanks to the predictions of what conditions were like in the primordial universe. Research indicates that the first stars release huge amounts of UV light, which could be absorbed by surrounding hydrogen atoms – an interaction that can affect the CMB.

"You start seeing the hydrogen gas in silhouette at particular radio frequencies," explains co-author Alan Rogers from MIT's Haystack Observatory. "This is the first real signal that stars are starting to form and starting to affect the medium around them."

This latest research has improved our understanding of the early universe and its formation



NEWS BY NUMBERS

2.3 million

people watched the live stream of the Falcon Heavy launch on YouTube

3,097

The number of Oscar statues given out in its 89-year history

$23bn

The estimated value of streaming company Spotify

1,059,646

The number of seeds now stored in the Svalbard Global Seed Vault

GLOBAL EYE

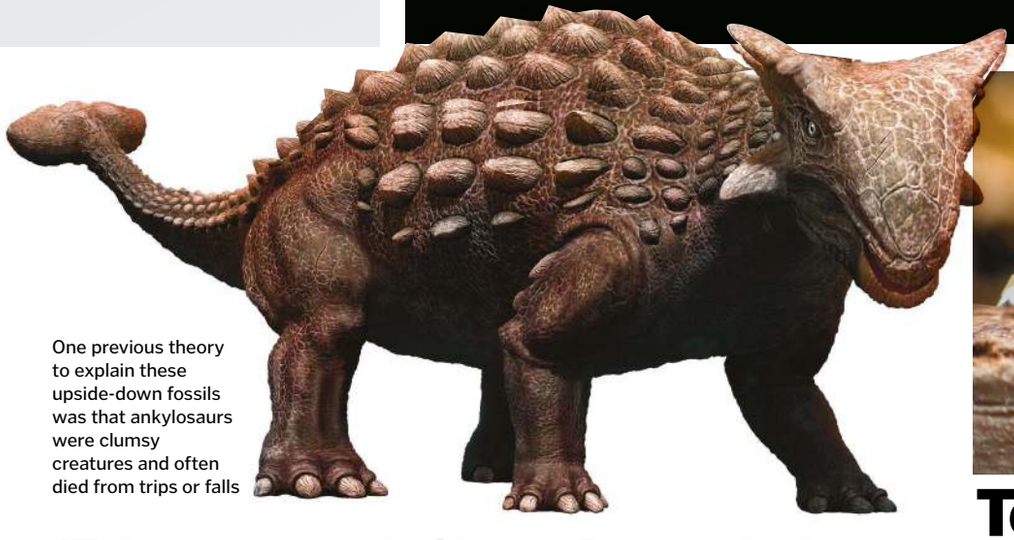
Genetically engineered molecules can target brain tumours

Reprogrammed immune cells can seek and destroy cancerous cells in the brain

A team of researchers from the US and Italy have developed a new way to treat glioblastoma, the most aggressive type of brain cancer. Genetically engineering immune cells to recognise the antigen CSPG4 (which is highly expressed by brain tumour cells) enabled the cells to home in on and attack the tumour. In mouse models of glioblastoma, using this approach led to increased survival rates and more controlled tumour growth.

The team plan to begin clinical trials of this innovative immune therapy in human glioblastoma patients, who typically do not survive more than 18 months with conventional treatments like surgery, radiation and chemotherapy.

This promising new treatment also targeted the cancer-initiating cells, helping to prevent regrowth of tumours



One previous theory to explain these upside-down fossils was that ankylosaurs were clumsy creatures and often died from trips or falls

‘Bloat-and-float’ explains strange fossil findings

A new theory could explain why so many ankylosaur remains are found upside-down

Dr Jordan Mallon, a palaeontologist from the Canadian Museum of Nature, has proposed a new explanation for why so many ankylosaur fossils are found in a belly-up position.

The ‘bloat-and-float’ theory suggests that the most likely explanation is that if the body of an ankylosaur washed into a river it would flip belly-side up due to the weight of the heavily armoured plates on its back. When its body eventually washed ashore, decomposed and fossilised, it would still be in this position, leaving an upside-down fossil for us to unearth millions of years later.

All termite species will be officially renamed within the cockroach order Blattodea

Termites are just social cockroaches

Scientists are updating this skilled insect’s official classifications

The Entomological Society of America are updating their master list of insect names to include termites within the same group as cockroaches, rather than their own taxonomic order. Over the past few decades there has been mounting evidence – including genetic research – to support the theory that the two insects are related. The debate goes back to at least 1934, when it was discovered that some groups of termites and cockroaches shared the same wood-eating microbes in their guts.

10 COOL THINGS WE LEARNED THIS MONTH

1 Growing up around greenery is good for the brain

A recent study has revealed that being raised in a greener neighbourhood could be beneficial to brain development. Using a high-resolution 3D magnetic resonance image (MRI), 253 children were scanned as part of a study, which found that primary school children who were raised in homes surrounded by green space presented larger volumes of white and grey matter in different areas of the brain. This increase has been associated with improved cognitive function.

2 Clever coatings could create smart windows

The development of a new hi-tech coating at RMIT University in Melbourne, Australia, is paving the way for 'smart windows'. These self-adjusting vanadium dioxide coatings will react to changing temperatures. When it gets hot, the coating becomes opaque to infrared radiation (to reduce solar heating) while remaining transparent to visible light so that it can still be seen through. Smart vanadium dioxide-coated windows are around 70 per cent more energy-efficient in the summer and 45 per cent more efficient during the winter compared to standard double-glazing, leading to significant energy savings and environmental benefits.

3 Horses descend from a spotty ancestor

A study of the family tree of modern-day horses has revealed that they descend from a horse with a Dalmatian-style coat. Researchers analysed genes of 88 ancient and modern horses from a range of eras across Eurasia. Previously believed to have descended from the Botai horses of Kazakhstan, the team discovered the true ancestors are the 'wild' Przewalski horses from the Mongolian region.

4 There's snake-shaped 'smoke' in space

Around 600 lightyears away, in the constellation of Scorpius, a serpentine region of 'smoke' has been imaged, illuminated by the light of newly formed stars. Known as Lupus 3, the cloud of smoke is in fact a dark nebula. This unusual shape is created by the stars' intense radiation and strong stellar winds, which have swept away the surrounding gas and dust.

5

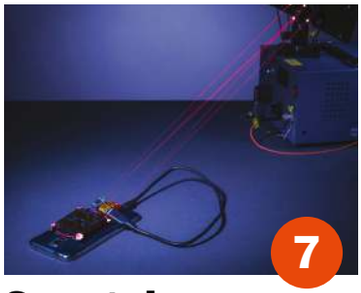
Elephants show different personalities just like humans

Researchers at the University of Turku, Finland, studied over 250 timber elephants in semi-captive natural habitats. Working alongside manouts, researchers conducted surveys between 2014 and 2017, assessing the elephants based on 28 different traits using a four-point scale. From the data collected, the team were able to identify three personality factors: attentiveness, sociability and aggressiveness.

6

Six new anteater species have been discovered

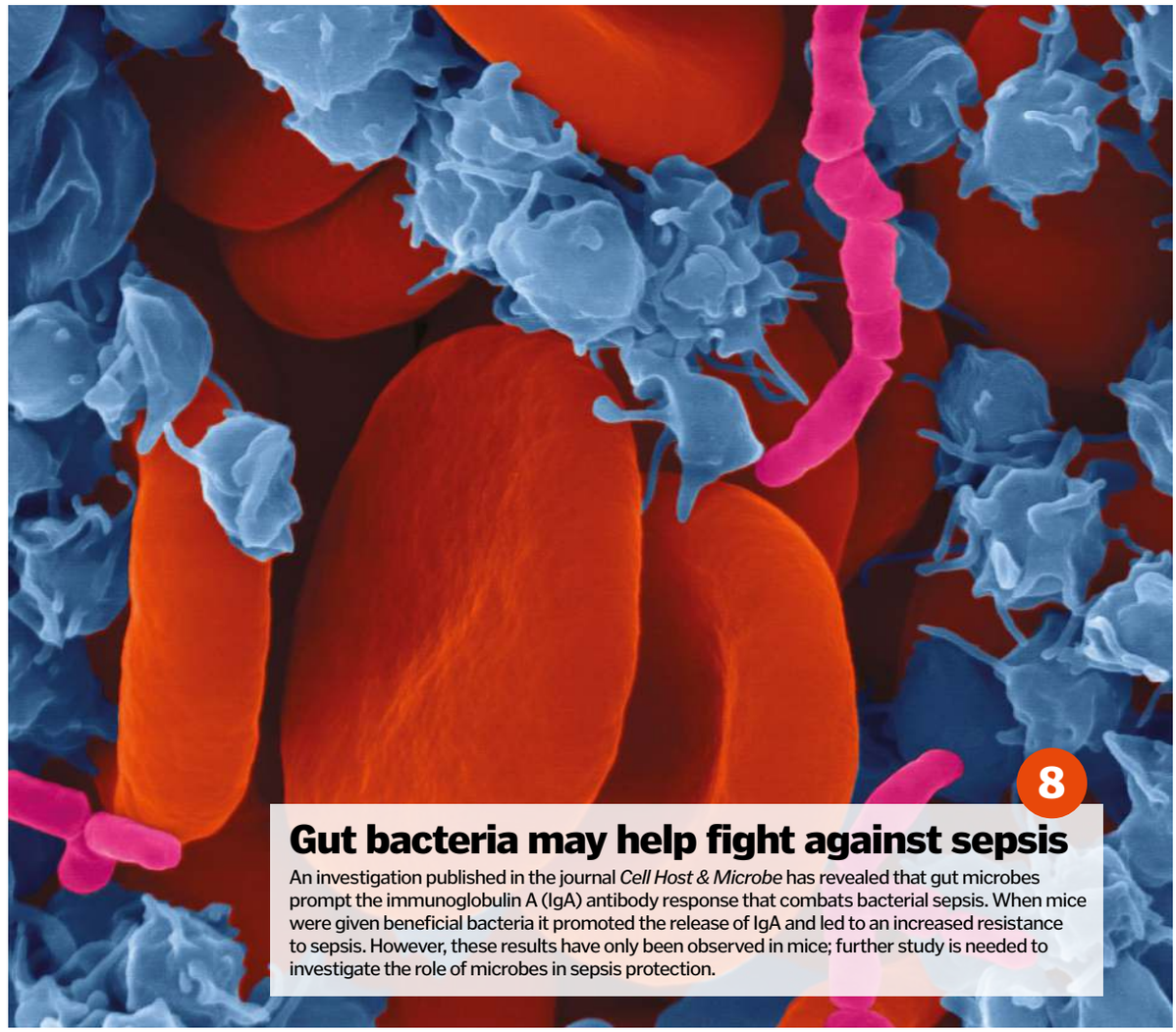
A group of Brazilian scientists have discovered six new species of silky anteaters scattered across South and Central America. They were previously believed to be seven separate populations of one species, but after genetically sequencing 287 specimens, the team revealed that the seven anteater sub-types were actually completely different species altogether.



7

Smartphones could be charged by lasers

Engineers at the University of Washington are developing a new technology to charge smartphones using an invisible laser. The laser beam would target a thin power cell on the back of phones to enable charging from a distance. Harmless 'guard beams' would also be used to detect people and turn the laser off as they pass.



8

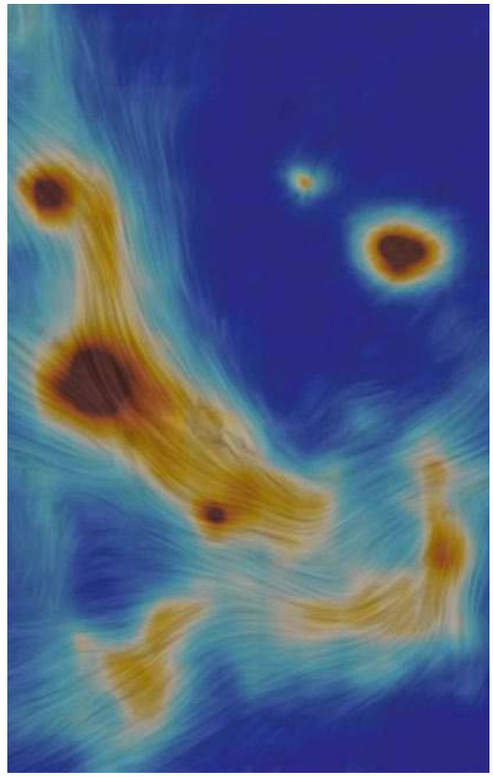
Gut bacteria may help fight against sepsis

An investigation published in the journal *Cell Host & Microbe* has revealed that gut microbes prompt the immunoglobulin A (IgA) antibody response that combats bacterial sepsis. When mice were given beneficial bacteria it promoted the release of IgA and led to an increased resistance to sepsis. However, these results have only been observed in mice; further study is needed to investigate the role of microbes in sepsis protection.

9

The clearest image of our galaxy's centre has been taken

A research team have produced a high-resolution map of the magnetic field lines in the gas and dust orbiting the supermassive black hole at the centre of our galaxy. By observing the infrared light, as well as X-rays and radio waves, the team were able to create an image of the magnetic fields interacting with the black hole (located at the centre of the image below).



10

Scorpion venom can treat arthritis

A new study suggests a treatment for rheumatoid arthritis could be derived from a component of scorpion venom. The substance, called iberiotoxin, may be able to block the potassium channels to a group of cells that play a major role in arthritis development. To date, research has been isolated to rat models. It found that iberiotoxin stopped progression and in some cases reversed signs of the already-established disease.

SUPER STEALTH

SONIC FIGHTER JETS

HOW THE FIFTH GENERATION OF FIGHTER AIRCRAFTS WILL CONQUER THE SKIES

Words by **Jonny O'Callaghan**

We've come a long way from the Wright brothers. Their first powered flight in 1903 consisted of a rudimentary wooden glider powered by propellers that reached a modest speed of 43 kilometres per hour. Now, more than a century later, a fleet of advanced supersonic stealth fighter jets are taking to the skies, capable of going undetected by radar and reaching speeds far in excess of the speed of sound – Mach 1 – which is around 1,235 kilometres per hour depending on air pressure and temperature.

The US was the first country to develop a so-called fifth-generation fighter with its F-22 aircraft, loosely defined as being a jet that has advanced stealth capabilities despite being armed, sleek designs to carve through the air and the capability of cruising at supersonic speeds without the use of fuel-hungry afterburners. But while the US currently dominates the field, Russia and China are quickly making headway, and many are already excited about what's next on the horizon, with artificial intelligence and autonomous flight all expected to play a part in the future of fighters.

Stealth fighter jets are iconic in their design and capabilities. They can enable rapid response to conflict, striking targets while remaining almost completely undetected. Their smooth and sleek bodies hide powerful weaponry under their skin, with the jets designed to have as few obtrusive parts as possible to give them a low radar cross-section (RCS). Powerful engines enable speeds of up to Mach 2, and pilots are given advanced helmets and technologies to help them locate and destroy targets.

"AI and autonomous flight are expected to play a part in future"

The US F-22 has been operational since 2005, but we've recently also seen the American F-35 – delayed by more than a decade and significantly over budget – enter service in 2015. The start of 2018, meanwhile, has seen both Russia and China's first stealth fighter jets; the Su-57 and J-20 respectively. Other countries including India, Japan and Turkey are now developing their own such vehicles as a new wave of advanced warfare takes place in the skies.

Over the next few pages we've run through some of the major players in stealth fighter jet technology and outlined some of the key features that make them so formidable. The Wright brothers may have changed the world with their fateful flight, but as the saying goes, you ain't seen nothing yet.

F-22 RAPTOR vs F-35 LIGHTNING II

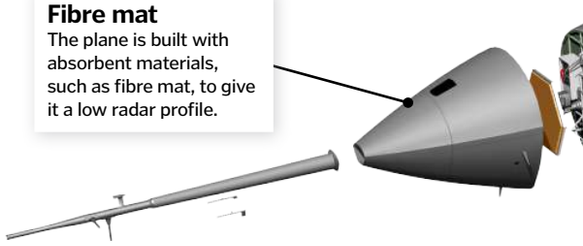
These American fighters are all but unmatched in the skies

At first glance, these two planes look quite similar, but beneath their exteriors lies very different technology. The F-22 Raptor, developed by Lockheed Martin and Boeing, has been in service since 2005, billed as the world's first stealth air-to-air fighter. Its curved body scatters incoming radio waves, ensuring the plane does not appear on scanners, and its weapons can be carried inside the fuselage, so it doesn't have any errant parts that might give its position away. It's capable of speeds of up to around Mach 2 and was the first US fighter able to 'supercruise', which means it can fly at supersonic speeds without using its afterburner, managing an impressive Mach 1.5 in this mode. This is thanks to two Pratt & Whitney F119-PW-100 engines.

Lockheed Martin's F-35 Lightning II Joint Strike Fighter (JSF), meanwhile, has a maximum speed of Mach 1.6. There are three variants: the F-35A, F-35B and F-35C, each with slightly different abilities. While it can't officially supercruise, it can maintain a speed of Mach 1.2 without its afterburners for a brief time, and like the F-22 it's designed to scatter radar waves and remain invisible on radar screens. It's outfitted with a single Pratt & Whitney F135 engine and, despite the delays, it's been described as one of the most advanced aircraft in the world. It's more suited to air-to-ground combat than the F-22, being able to carry more powerful bombs. Although it flew for the first time in 2006, it didn't enter service until 2015.

"The F-35 is one of the most advanced aircraft in the world"

Fibre mat
The plane is built with absorbent materials, such as fibre mat, to give it a low radar profile.



Battle of the beasts

How these two advanced aircraft stack up against one other

F-22 KEY STATS

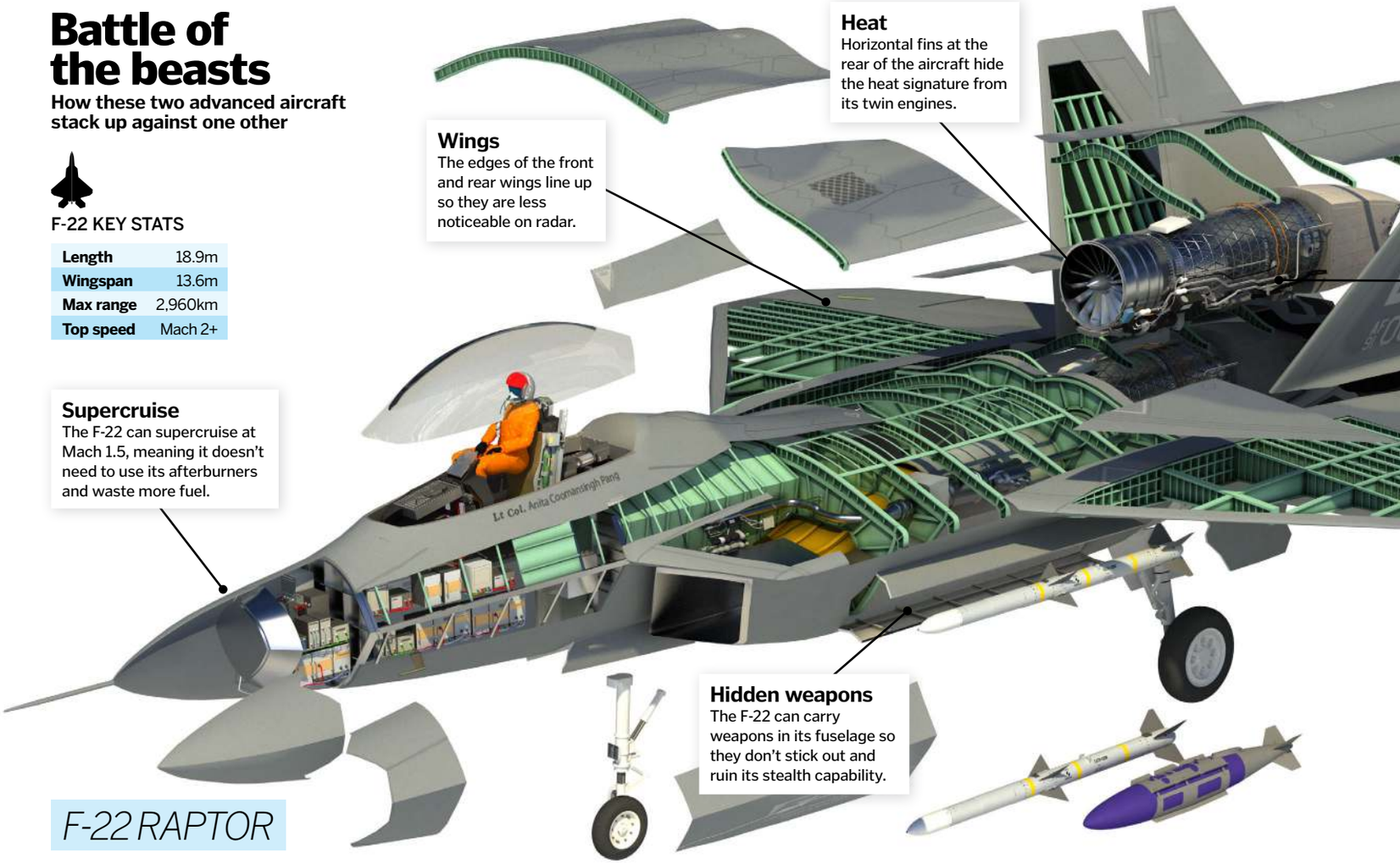
Length	18.9m
Wingspan	13.6m
Max range	2,960km
Top speed	Mach 2+

Heat
Horizontal fins at the rear of the aircraft hide the heat signature from its twin engines.

Wings
The edges of the front and rear wings line up so they are less noticeable on radar.

Supercruise
The F-22 can supercruise at Mach 1.5, meaning it doesn't need to use its afterburners and waste more fuel.

Hidden weapons
The F-22 can carry weapons in its fuselage so they don't stick out and ruin its stealth capability.



F-22 RAPTOR

F-35 LIGHTNING II

Advanced electronic warfare
Pilots in the F-35 can track enemy forces, jam radars and more with its high-tech capabilities.

Engine intake
The air intakes for the engine are designed to be hard to spot by radar.

Supersonic
The single F135 engine enables the F-35 to reach up to Mach 1.6.

Vertical landing
The F-35B variant can take off, hover and land vertically by rotating its engine downwards.

Fins
The two large, vertical fins are angled to deflect incoming radar waves.

Afterburners
Two F119 engines enable this aircraft to reach a blistering Mach 2.

F-35A KEY STATS

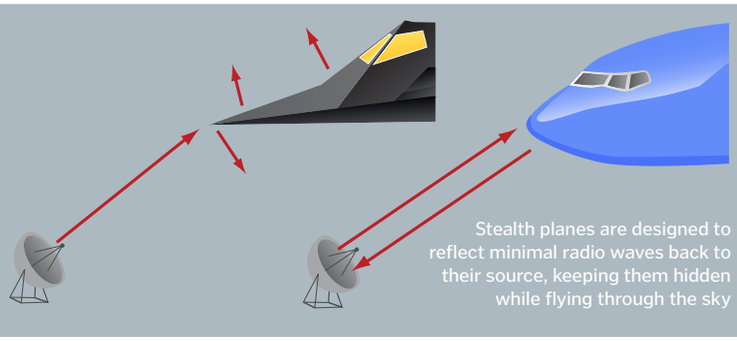
Length	15.7m
Wingspan	10.7m
Max range	2,200km
Top speed	Mach 1.6

The F-35 is the newest American fifth-generation fighter

The iconic B-2 bomber used stealth technology to deliver bombs undetected

Stealth technology

Radar systems are able to see planes by bouncing radio waves off them then measuring the time taken for the reflection to return to determine the position of the aircraft. But what if the waves never return? That's the basic idea around stealth planes, which are designed to reflect or scatter waves so that they go undetected. Some do this with their design, using conjoined edges and smooth surfaces to achieve a low RCS – the lower the better. Others use materials that absorb radar signals in order to produce a similar effect. While some stealth aircraft have a lower RCS than others, each fifth-generation fighter is able to keep itself hidden before it's time to strike.



Stealth planes are designed to reflect minimal radio waves back to their source, keeping them hidden while flying through the sky

SUKHOI SU-57

How does Russia's first stealth fighter stand up to the American's?

The Su-57 is Russia's first operational stealth fighter

Russia's Su-57 (also known as the PAK FA Tu-50), developed by manufacturer Sukhoi, recently came into service when it was deployed to Syria in February 2018. The aircraft, billed as a fifth-generation fighter, is the first Russian aircraft to employ stealth technology. Like the F-22, this plane is designed to scatter and deflect radar waves, using sawtooth edges and angled wings to keep the plane out of radar sight. The Su-57 can reach an impressive Mach 2 using a pair of Type 117 engine, and it can supercruise at Mach 1.6. This makes it faster than both the F-22 and F-35.

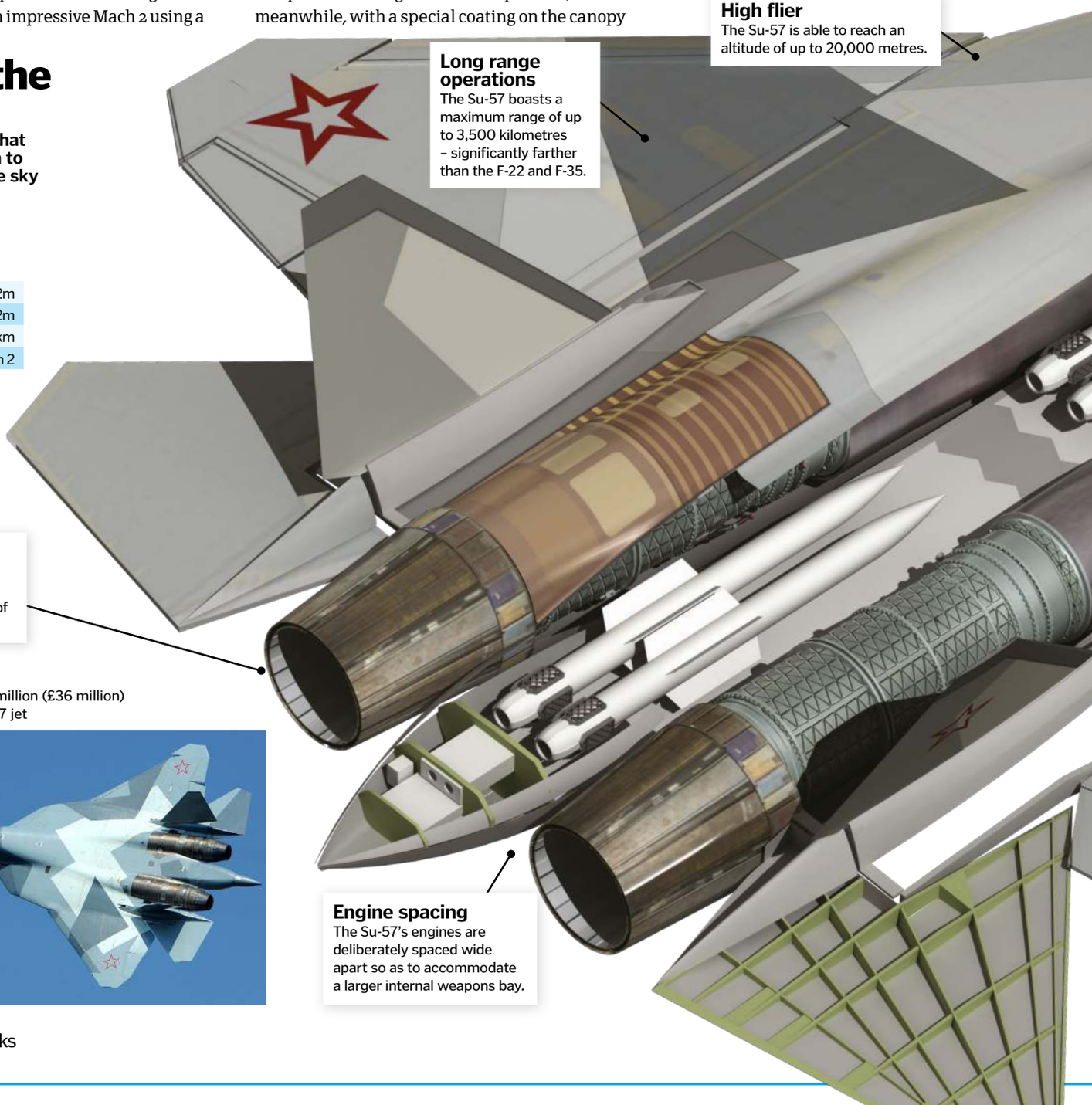
Like those two planes, the Su-57 carries its weapons in hidden bays, keeping it invisible to radar. It also uses radar-absorbing and radar-shielding materials and coatings to reduce its RCS, in addition to radar blockers. The cockpit and pilot's radar signature are kept small, meanwhile, with a special coating on the canopy of the plane. However, the Su-57 has come under some criticism for still having an RCS of 0.3 to 0.5 square metres, compared to just 0.0001 and 0.001 square metres for the F-22 and F-35 respectively, meaning its stealth capabilities are perhaps not as impressive. Nonetheless, it is a formidable aircraft, with a top speed that can't be bested by its American counterparts.

Inside the Su-57

The technology that may allow Russia to rival the US in the sky

KEY STATS

Length	22m
Wingspan	14.2m
Max range	3,500km
Top speed	Mach 2



High flier
The Su-57 is able to reach an altitude of up to 20,000 metres.

Long range operations
The Su-57 boasts a maximum range of up to 3,500 kilometres – significantly farther than the F-22 and F-35.

Engines
A pair of Type 117 engines propel the plane up to speeds of around Mach 2.

Engine spacing
The Su-57's engines are deliberately spaced wide apart so as to accommodate a larger internal weapons bay.

It costs around $50 million (£36 million) to build a single Su-57 jet

A senior Russian official has stated that the Su-57 could be upgraded to become a 6th-generation fighter

"The Su-57 can reach Mach 2 and supercruise at Mach 1.6, making it faster than the F-22 and F-35"

Size
At 22 metres long, and with a wingspan of 14.2 metres, the jet is slightly on the large side for a fighter jet.

Cockpit
The cockpit is covered in a coating to hide the radar signature of the pilot.

Missile sensor
Located behind the cockpit, the upper-hemisphere missile approach warning will alert the pilot to incoming missiles.

Hidden arms
Like the F-22 and F-35, the Su-57 keeps its weapons hidden.

Cloaking coating
The plane is coated in radar-absorbing and radar-shielding materials.

Stealth silhouette
The edges of the plane are aligned to reduce its radar signature.

Chengdu J-20

China's foray into the world of fifth-generation fighters is the somewhat mysterious Chengdu J-20 stealth fighter, developed by the Chengdu Aerospace Corporation. It is China's first stealth fighter, capable of achieving speeds of up to Mach 2. The J-20 is powered by two turbofan engines with afterburn capabilities, with three internal bays in its fuselage to hide weapons. It's believed to have field signature reduction technology that helps keep it hidden. It's shaped in a similar way to the F-22 to minimise its radar signature, although some doubts have been raised about its engine nozzles, which may expose it to radar. It flew for the first time in 2011 but officially entered service in September 2017, making it the world's fourth fifth-generation stealth fighter.

Many features of the Chengdu J-20 are still largely unknown

The Chengdu J-20 is one of two fighter jets being developed in China

FUTURE STEALTH FIGHTERS

What can we expect from the next generation of advanced jets?

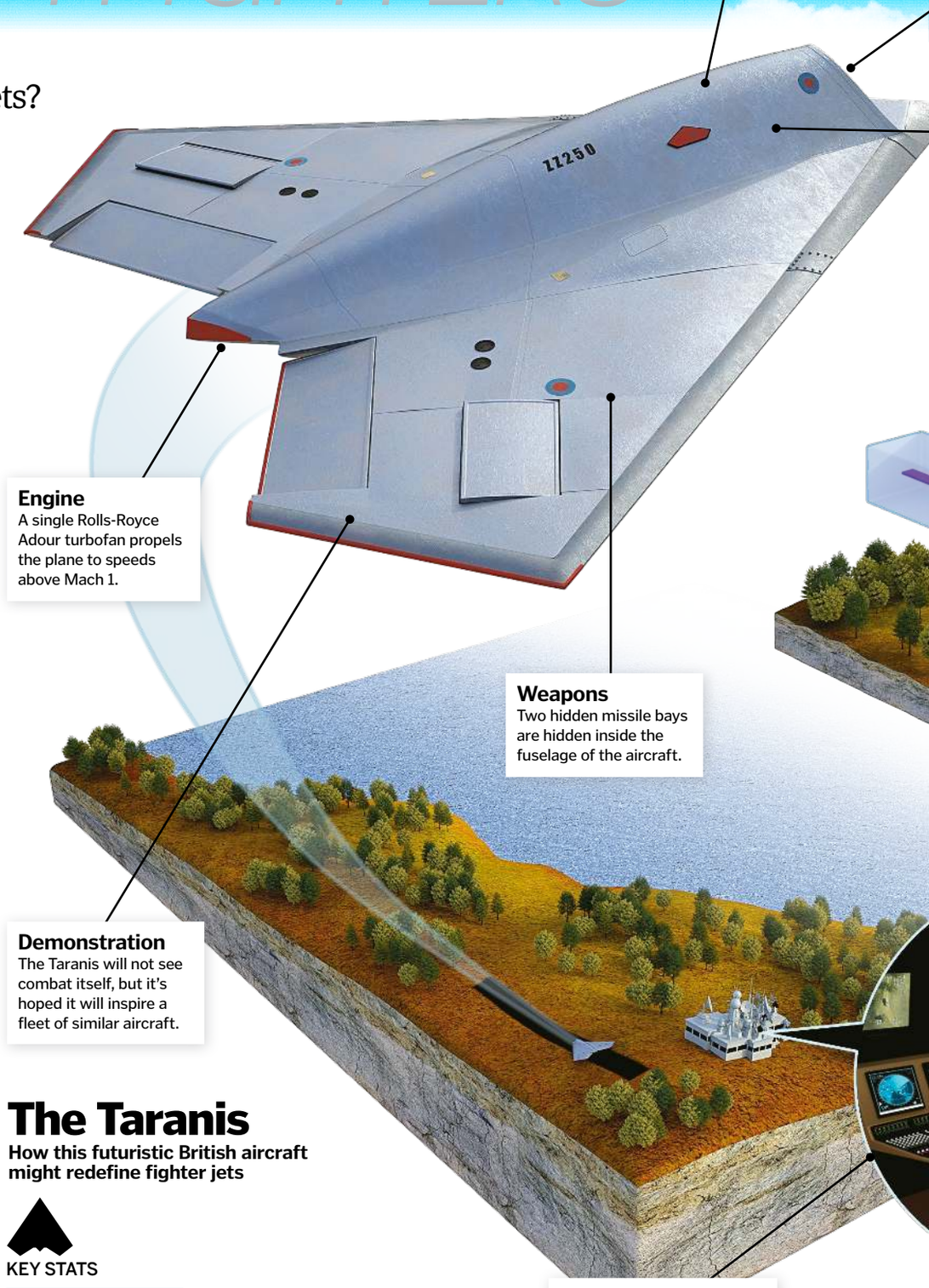
Some of the aircraft on these pages may have wowed you so far, but in the future we're promised even more impressive technologies leading up to the sixth generation of fighters. Some of these will include advanced artificial intelligence and may even be operated without a human pilot onboard as countries around the world aim to modernise their air forces.

These aircraft will boast extended ranges to strike distant locations, and some may even include a second pilot to coordinate a fleet of additional unmanned vehicles. Others may have sensors built into the skin of the aircraft to hide them from radar view, while some could even possess hypersonic weaponry – those that can reach or exceed Mach 5.

One particularly impressive plane in development is the Taranis from BAE Systems in the UK. This uncrewed vehicle flew for the first time in 2013, and its technology is designed around intercontinental missions. Controlled by a human on the ground, it is capable of speeds of more than Mach 1 – but it's the remote control aspect that really makes it a fearsome future weapon. Yet while it boasts stealth technology alongside its supersonic capabilities, it won't see combat itself. Instead, a successor will be developed to enter service in the 2030s that will incorporate its technologies.

Boeing, meanwhile, is hard at work on a sixth-generation fighter as part of its F/A-XX programme. As yet unnamed and mostly under wraps, we do know the jet will have no tail and will sport a similar sensor system to the F-35. It's designed to be both fast and stealthy, with its wings angled almost like a rhombus to reduce its radar signature. It's hoped that it will enter service at some point in the 2030s, replacing the US Navy's Super Hornet aircraft.

Then there's the B-21 Raider, a stealth bomber being designed by the US company Northrup Grumman. It's not known yet if it will be supersonic, but we do know it's designed to be able to deliver precision strikes anywhere in the world. It will have a bat-like wing design and stealth capabilities to keep it hidden. Early versions are likely to be crewed, but it's possible there could be uncrewed versions in the future.



Stealth
The sleek, angled design of the jet ensures that it isn't picked up by radar.

Engine
A single Rolls-Royce Adour turbofan propels the plane to speeds above Mach 1.

Weapons
Two hidden missile bays are hidden inside the fuselage of the aircraft.

Demonstration
The Taranis will not see combat itself, but it's hoped it will inspire a fleet of similar aircraft.

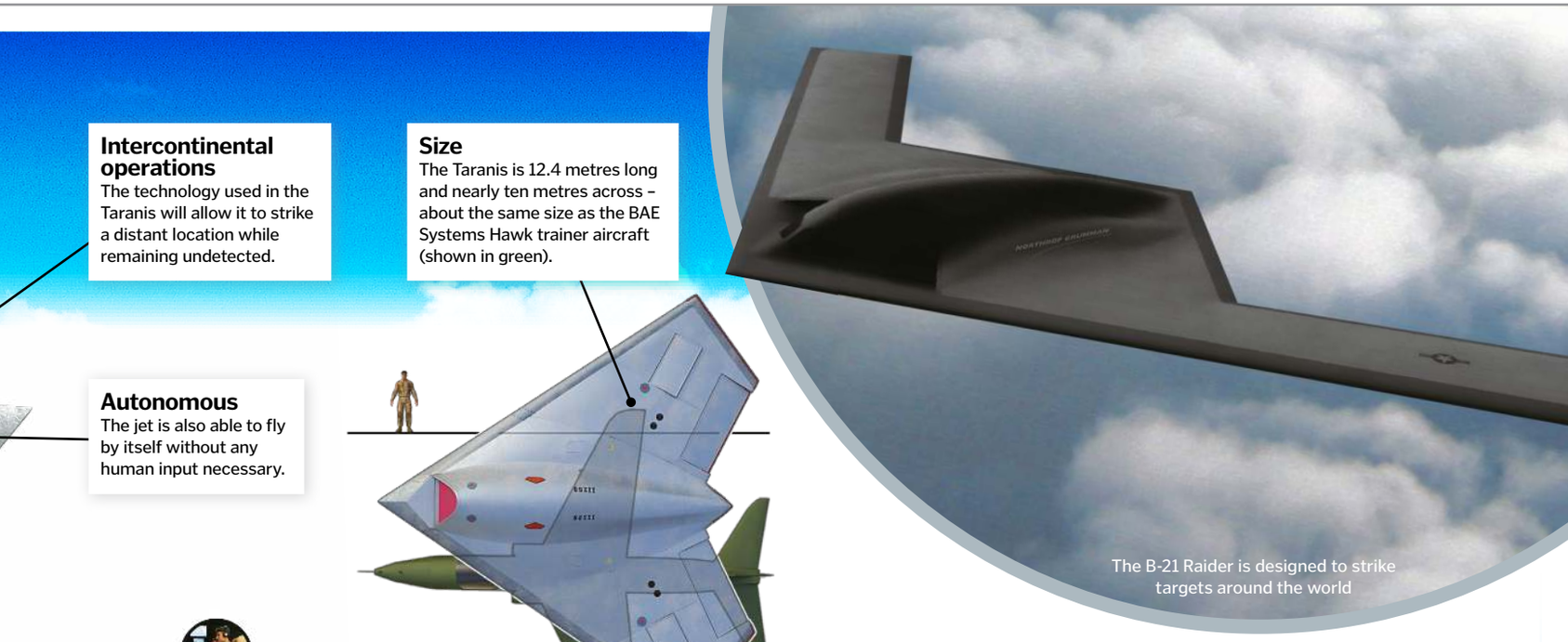
Remote control
The Taranis is uncrewed, designed instead to be flown by a remote operator.

The Taranis

How this futuristic British aircraft might redefine fighter jets

KEY STATS

Length	12.4m
Wingspan	9.8m
Max range	Unknown
Top speed	Mach 1+

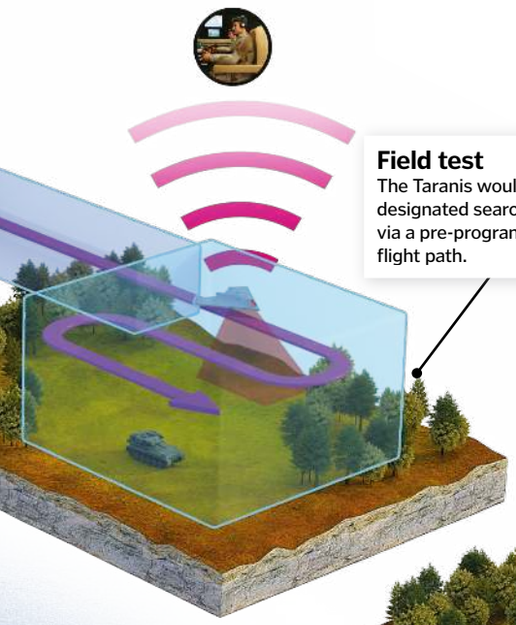


The B-21 Raider is designed to strike targets around the world

Intercontinental operations
The technology used in the Taranis will allow it to strike a distant location while remaining undetected.

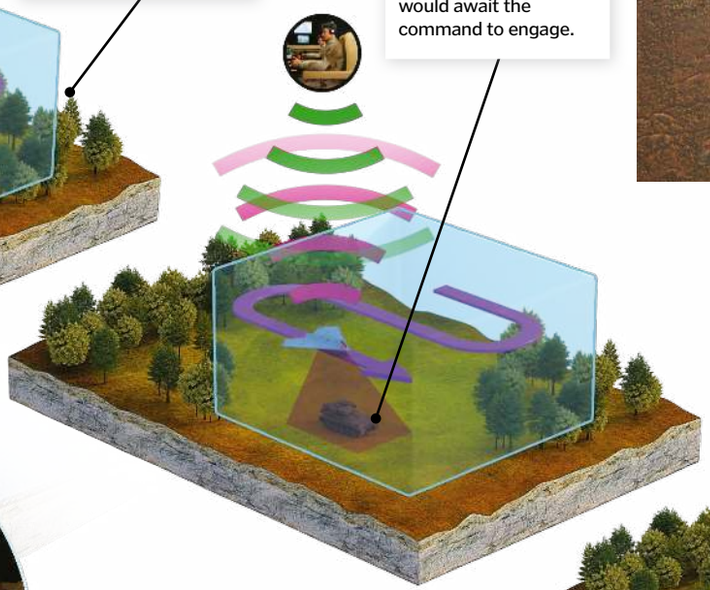
Size
The Taranis is 12.4 metres long and nearly ten metres across – about the same size as the BAE Systems Hawk trainer aircraft (shown in green).

Autonomous
The jet is also able to fly by itself without any human input necessary.



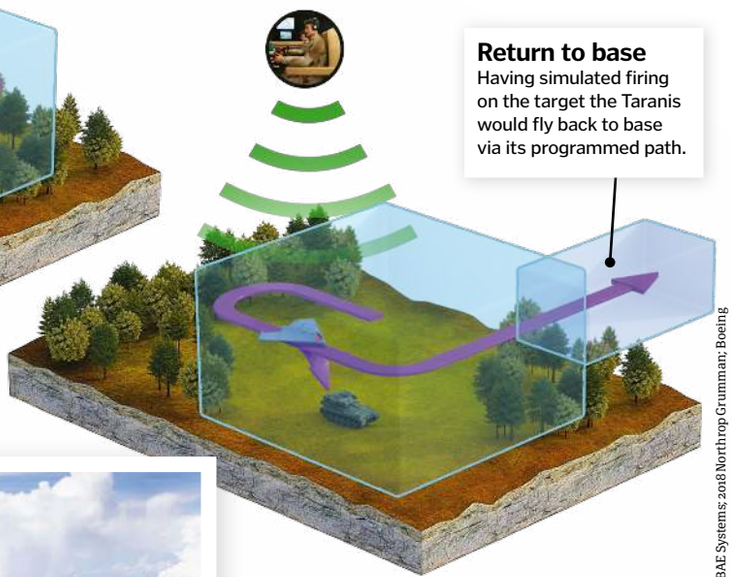
Field test
The Taranis would fly to a designated search area via a pre-programmed 3D flight path.

Target acquired
Having located the target the Taranis would await the command to engage.



The Taranis performed its first test flight in Australia in 2013

Return to base
Having simulated firing on the target the Taranis would fly back to base via its programmed path.



Boeing's F/A-XX is one of the first sixth-generation fighter jet concepts to be revealed so far

"Future jets could carry hypersonic weapons"

How cars are painted

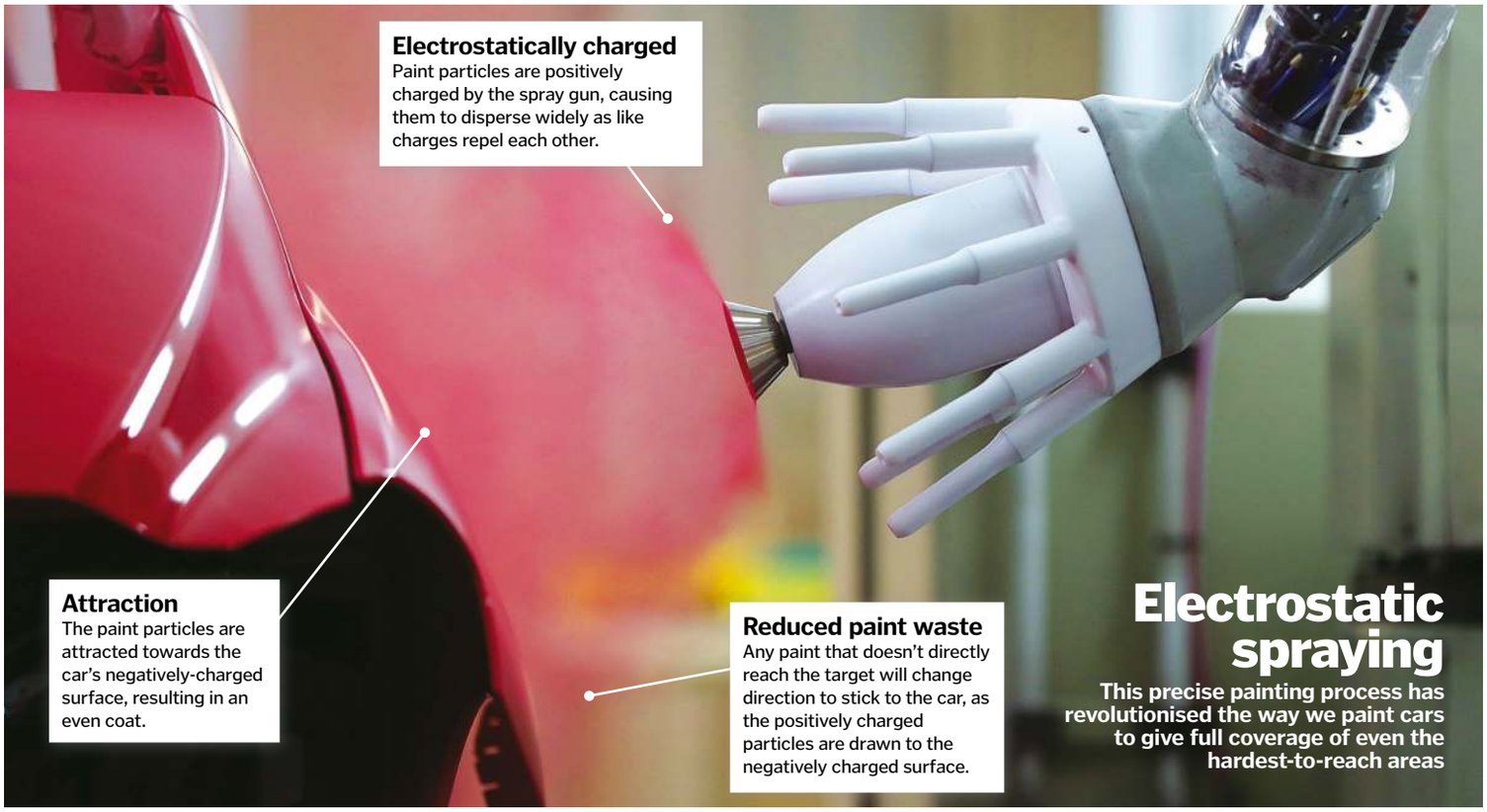
A vehicle's colours and coatings are more than just decorative – they also provide protection

Whether your car is bright orange or plain white, the perfect paint job is not just about the colour – it's also there to preserve and protect your vehicle from the elements.

After the bare metal shell of a car is formed, the first step in the painting process is to clean it and apply a corrosion-resistant layer using a series of dip tanks. This must be done thoroughly, as even the smallest smudge from a human hand could affect the finish.

The base and top coats of paint are applied using electrostatic spray guns, which ensure the paint is applied evenly. Finally, a clear lacquer coating is applied to protect the car against the elements, including UV radiation and dirt.

At several stages between coats the car is heat-cured in a specially designed oven to strengthen the coatings (providing scratch and chip resistance) and to remove any unwanted moisture. When complete, these carefully applied layers will ensure that your car's bodywork will survive for many years to come, whatever the weather.



Noise-reducing roads

How do new surfaces absorb or redirect sound to help make driving quieter?

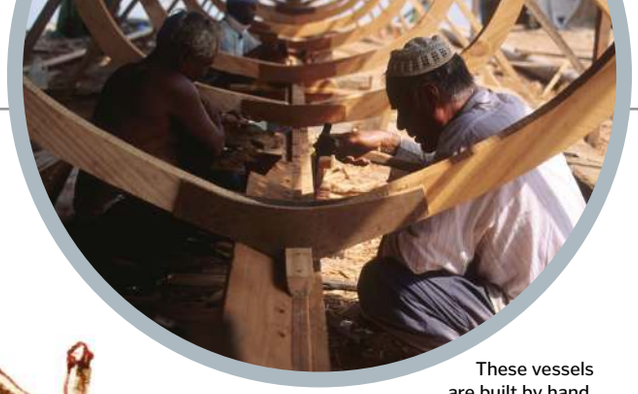
Road noise pollution is a source of growing frustration for many, but it isn't just roaring engines – it's also the sound of the vehicles rolling over the road.

Low-noise road surfaces are a cost-effective solution; they are better than noise screens or insulation at reducing the level of sleep disturbance and stress impacting people living in heavy traffic areas.

Low-noise roads can be made in several different ways, and road construction workers will select the most suitable method after considering the needs of the local area and budget. Some roads will use a base of small aggregate (chunks or grains of crushed rock) to minimise the vibration of tyres driving along the surface, which can be made even quieter when made of porous material as air pockets also provide some insulation.

Some noise-reducing roads will use larger, coarser aggregate that is laid with deliberate gaps to absorb sound. Other options include two-layer porous asphalt, which consists of a thin, small-aggregate top layer and a thick, course-aggregate bottom layer. This method is usually reserved for high-speed roads.

You may notice the difference in noise level when driving between old and new road surfaces



These vessels are built by hand, with larger cargo-carrying dhows taking several years to build

Back to basics

What enables these vessels to sail the seas?

Steering
The triangular lateen sails are held up by either one or two masts affixed by a long yard or crossbar for adjustable control depending on wind direction.

Preservation
In order to preserve the wood from damage from barnacles, for example, goat fat and lime are rubbed on the hull. Coconut rope used in construction is also coated in vegetable oil to preserve it.

Waterproof
In order to prevent water from entering the boat, lime and tree gum were traditionally used to seal the wood construction, while a marine varnish is used in modern dhows.

Construction
Dhows are made using a shell-building method, which entails carving its shape using hand tools, one wooden plank at a time. Planks are traditionally held together with rope, but modern-day dhows' planks are securely fastened with nails.

Discover the dhow

The handmade boats hitching a ride on the winds of the Indian Ocean

Used as fishing, freight and passenger vessels, possibly for more than 2,000 years, dhows are built entirely by hand with no blueprints to refer to. The exact origin of these boats remains unclear, but they can be found in the docks of the majority of countries that border the Indian Ocean.

Traditional dhows are made completely of wood; the hull and keel timbers are mainly mahogany or ekki and the masts are made from teak and/or coconut wood. It's the design of its sail, however, that allows these vessels to tackle the changing winds of the Indian Ocean.

Dhows use a fore-and-aft sailing rig alignment to propel the boat across the water. This method uses a triangular sail, known as a lateen, as opposed to a square one. Running along the length of the vessel, dhows hitch a ride on the upward thrust of wind caught in its slack sail. The ingenuity in the design of these sails lies in their ability to turn and face whichever way the wind is blowing, rather than relying on the wind coming up from behind. This navigational feature has also allowed the vessels to be used in racing competitions.

Traditional dhows come in a wide range of shapes and sizes, but their characteristic sail always remains the same. However, some modern-day dhows have swapped out their sails for engines.

Dhows are now used in boat racing – a popular contest is the Al Gaffal race in Dubai

The Tesla Semi

Why the all-electric pioneers are now targeting trucks

As part of the global effort to reduce greenhouse gas emissions, several countries have pledged to ban petrol and diesel vehicles within the next few decades. While the market for hybrid and electric cars has grown in reply, these bans will also apply to commercial vehicles such as lorries

Unsurprisingly, these larger vehicles are responsible for a considerable amount of pollution. In the EU, lorries, buses and coaches produce around 25 per cent of all road transport carbon dioxide emissions and about five per cent of the EU's greenhouse gas emissions overall – more than the aviation or shipping industries.

So far, achieving a viable range with battery power has been a major roadblock for electric lorries, which typically need to make long-distance journeys. Enter the game-changer: the Tesla Semi – a fully electric truck capable of achieving ranges of over 800 kilometres on a single charge. Four powerful motors deliver instant torque, which can take it from 0–100 kilometres per hour in just 20 seconds while fully loaded with over 36,000 kilograms of cargo. The battery-powered beast can even tackle slopes with a five per cent incline at nearly 105 kilometres per hour.

Tesla claim the Semi is "the safest, most comfortable truck ever", featuring an Enhanced Autopilot system to help avoid collisions and a low centre of gravity to reduce the risk of a rollover. It also boasts a very low cost of ownership compared to conventional lorries. Electric vehicles have fewer moving parts than combustion engine vehicles, so there are fewer components to maintain. It is also estimated that the Semi would save owners around $200,000 (approximately £145,000) in fuel costs over the vehicle's lifetime.

So could this all-electric truck be the future of freight? Production of the Semi is expected to begin in 2019, but some companies – including Walmart, Pepsi, UPS and DHL – have already placed their first orders. However, where electric vehicles are concerned, Tesla have a track record of setting the benchmark for competitors to meet or beat. Perhaps we'll see other manufacturers following suit, with a whole host of electric lorry models on our roads before long.

Improved safety

Jackknifing is a serious danger to articulated lorry drivers. The Semi's onboard sensors can detect if there is instability in the wheels, and compensate by providing the required corrective torque to each wheel – a feature that Tesla claim will make jackknifing impossible.

Tesla's e-truck

Find out why the Semi will leave gasoline guzzlers in the dust

Streamlined

The Semi's wedge-like shape makes it more aerodynamic. Its drag coefficient – a measure of the air resistance an object experiences – is around half that of conventional trucks and even lower than that of the Bugatti Chiron supercar.

Enhanced Autopilot

All Tesla Semis will come with autopilot functions as standard, including emergency braking, lane keeping and forward collision warning. Cameras around the cab minimise blind spots and help with object detection.

Instant torque

Electric motors can provide maximum torque (a rotational force) to the wheels instantaneously, providing quick acceleration. The Semi can reach 100kph three times faster than an equivalent, conventional truck.

"In the EU, lorries, buses and coaches produce more greenhouse gas emissions than aviation or shipping"

Tesla Armour Glass
Chips or cracks in windshields can put trucks out of action as they wait for repairs. According to CEO Elon Musk, the Semi's impact-resistant windshield "survives a nuclear explosion or you get a full refund".

Smooth ride
With an electric motor there are no gears to shift through, so acceleration and deceleration is supersmooth.

Central driver seat
The driver is positioned in the middle of the cab, providing maximum visibility. Two large touchscreen instrument panels either side of the wheel will display journey and vehicle information.

Recharging vs refuelling

One hurdle that faces electric vehicles in general is their charging times. On a long journey you can refuel your car in a matter of minutes, but charging an electric model takes considerably longer – with current technology at least.

However, since lorries have such large fuel tanks, refuelling can take 15 minutes or more, and drivers are legally required to take breaks during long shifts. Taking these points into consideration, recharging times could feasibly be factored into a driver's normal routine.

Tesla plan to develop a global network of solar-powered, high-speed 'Megachargers', which in 30 minutes would provide enough charge to travel over 640 kilometres. The aim is to have these stations available at a truck's origin point and destination, and along busy routes. This would allow drivers to recharge as they load or unload their cargo, or while taking one of their designated breaks.

Similar to their Supercharger stations (pictured), Tesla hope to install a network of solar-powered Megachargers to support Semi drivers

Regenerative braking
Stopping a large, heavy truck travelling at speed requires a lot of energy. The Semi's brakes can act like generators to harvest up to 98 per cent of this otherwise wasted energy to recharge the batteries.

Batteries
The battery pack is reinforced to protect against damage, and stores enough energy to provide a range of nearly 805km.

Reduced noise
Without loud engines, electric trucks will be much quieter than conventional ones, helping to reduce noise pollution on our roads.

With onboard autonomous technologies, a convoy of Semis will be able to follow a lead driver

CEO Elon Musk showed off the Semi's impressive capabilities at a launch event in November 2017

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FLOATING C
The future of urb

As the pollution and populations in our cities boom, is it time to set our sights on the sea?

Words by **Charlie Evans**

Clean air
The LilyPad's titanium-dioxide-coated skin will react to the Sun's ultraviolet rays, enabling it to absorb atmospheric pollution by a photocatalytic reaction.

Safe haven
The self-sufficient amphibious city would aim to host 50,000 climate change refugees. It is hoped that this concept could be made a reality by 2100.

With our cities more packed and polluted than ever, engineers and architects are being forced to get creative. In the face of a growing population we've built staggering skyscrapers and deep underground networks of transportation systems, but where do we go next? Some have started to look at the final unclaimed frontier – the ocean.

It's an idea that sounds as if its been taken out of a science fiction movie, but seasteading (the idea of building permanent settlements at sea) has materialised into a quickly approaching reality. Whether designers are looking at up-scaling cruise ships into giant city vessels or crafting individual floating homes attached to one another in the sea, the quest to find eco-friendly, self-governing alternatives to land-based cities has begun.

It might sound like an idea far from our reach, but the knowledge we need to move into the oceans already exists – it's now only a case of experimenting and trialling existing technologies together to overcome the challenges associated with life in the great blue, and the motivation to do just that is becoming more and more apparent.

Our planet is facing the imminent threat of rising water levels. Since the beginning of the 20th century, sea levels have risen by about 20

ITIES an life

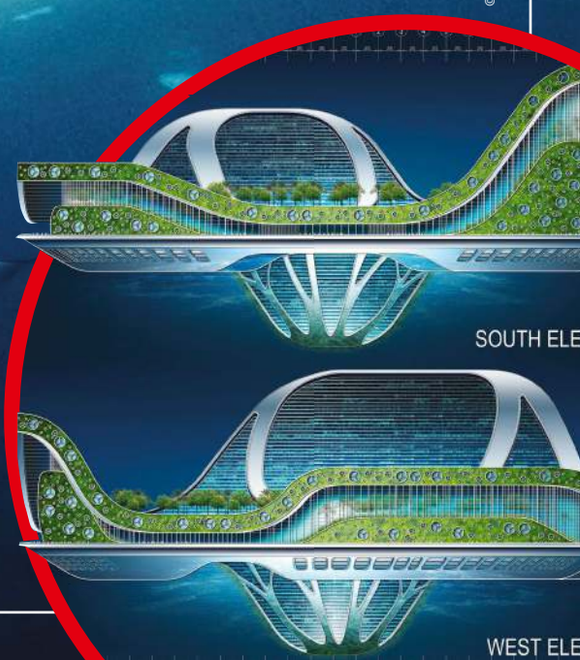
Aesthetic environment
The scenery on the LilyPad will include an artificial lagoon and three mountain-like ridges to create a diverse environment for the inhabitants, as well as nurturing a range of fauna and flora.

Energy
The concept would utilise a range of renewable sources – including solar, thermal, wind, hydraulic and tidal – to generate more energy than it consumes.

Biomimicry
The LilyPad's design is inspired by its namesake; Victoria water lilies have large, ribbed leaves that float on the water's surface.

All adrift
LilyPad would drift across the oceans with the currents, like the Gulf and Labrador streams.

Aquaculture
Farms below the water's surface would be used to grow food, which could also be used as biomass for energy production.



"The quest to find eco-friendly, self-governing alternatives to land-based cities has begun"

The blueprints for the LilyPad project are extensive, though currently it remains more of a dream than a reality due to the expensive start-up costs

centimetres, and it is predicted that the oceans will rise by around 65 centimetres by 2100. Scientists estimate that 275 million people worldwide are currently living in areas that will be submerged if the global temperature rises by three degrees Celsius. If global warming continues, the famous beaches of Rio de Janeiro in Brazil will soon be underwater; Shanghai in China, with its population of over 24 million people, will be completely destroyed; and Miami in the US will see more than just knee-deep water flooding the town. Without a solution, this will cause large-scale devastation and loss of life, with millions of people's homes and livelihoods being destroyed. This has inspired companies to begin forming plans to build cities out at sea to ensure we stay high and dry.

The projects are challenging, as many factors need to be considered: how would a floating city react to a natural disaster such as a hurricane; how would the community grow food or access drinkable water? The first major challenge for engineers working on seasteading projects is finding the balance between a structure that is strong enough to be stable, but flexible enough to roll when the waves come. Many have focused their attention on designing multiple small but sturdy platforms that can be interlocked together, creating a flexible membrane that will float on the surface.

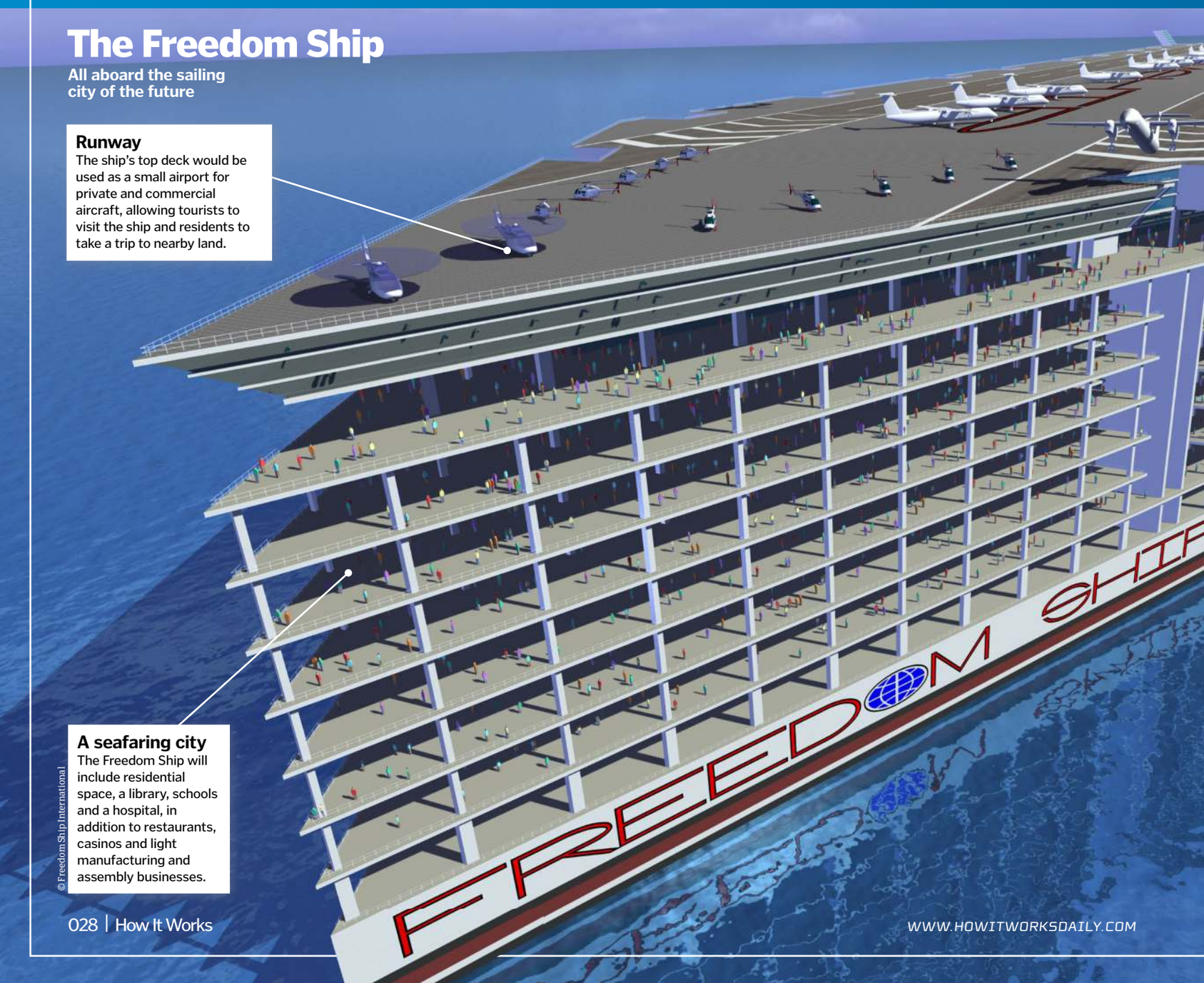
Many of the designs – like many of the greatest engineering projects – are inspired by nature, which has already developed the perfect floating island design in the form of tussocks. These clusters of plants grow on a carpet of buoyant roots (containing oxygen bubbles that help to keep them afloat) while they travel with the wind direction. Other engineers have used cruise ships as a model, seeking to scale them up to house hundreds of thousands of passengers, but this approach brings its own set of problems.

Why can you comfortably sit on a cruise ship sipping a cocktail but you struggle to walk across a canoe without falling into the water? The key is keeping a low centre of gravity and distributing weight over a large surface area. A large boat has an enormous bulkhead that protrudes outwards into the sea to balance the weight on top so it that can be distributed evenly, but with a smaller vessel the centre of gravity is higher due to the lack of a giant bulkhead and will therefore rock with small movements.

There are already half-a-kilometre-long tankers roaming our seas, but there is a limit to the size that can be built. To build a permanent city on a boat, the bulkhead would

The Freedom Ship

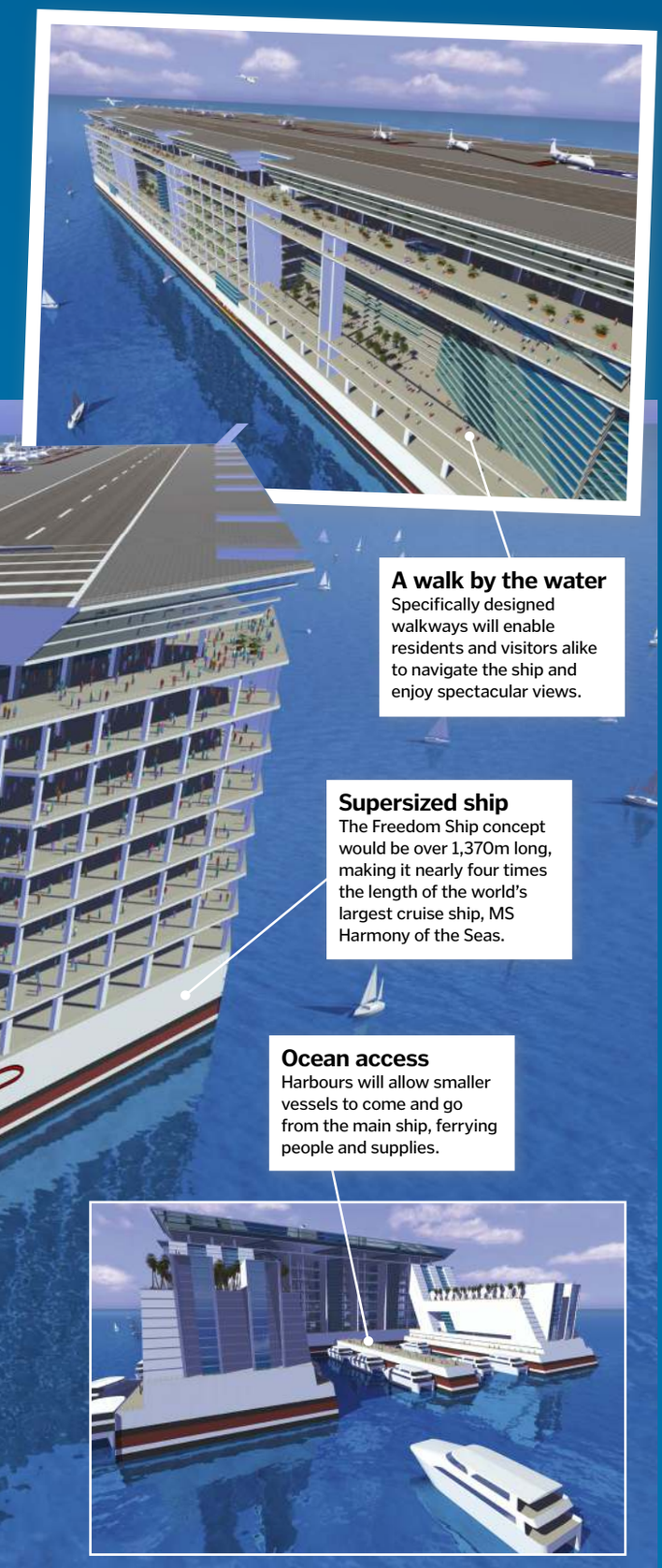
All aboard the sailing city of the future



Runway
The ship's top deck would be used as a small airport for private and commercial aircraft, allowing tourists to visit the ship and residents to take a trip to nearby land.

A seafaring city
The Freedom Ship will include residential space, a library, schools and a hospital, in addition to restaurants, casinos and light manufacturing and assembly businesses.

"The famous beaches of Rio de Janeiro will be underwater; Shanghai will be destroyed"



A walk by the water
Specifically designed walkways will enable residents and visitors alike to navigate the ship and enjoy spectacular views.

Supersized ship
The Freedom Ship concept would be over 1,370m long, making it nearly four times the length of the world's largest cruise ship, MS Harmony of the Seas.

Ocean access
Harbours will allow smaller vessels to come and go from the main ship, ferrying people and supplies.

PLAIN SAILING OR A PERFECT STORM?

Weighing up the advantages and disadvantages of floating cities

ADVANTAGES

Solution to rising sea levels
As sea levels rise and populations increase, we are finding ourselves with less land. Without somewhere to resettle, the next decade will see a rise in climate change refugees. Floating cities could provide an alternative home for them.

Freedom and mobility
Floating cities in the open ocean will be politically and geographically free. They will be able to move out of the path of hurricanes, travel with fish supplies, relocate to better weather conditions and leave for other neighbourhoods.

Sustainable future
The concepts for floating cities are designed to be cleaner and greener than our current land-based cities, many of them utilising the ocean as a source of infinite electricity that doesn't harm the environment in any way.

Quality of life
Living on the open ocean in an eco-friendly micronation will drastically increase the quality of life, as it will result in greater social cohesion as well as a massive reduction in air pollution and overcrowding.

Chance to rebuild
Cities today are riddled with restrictions on their existing infrastructure, but being able to move into the ocean would provide the opportunity to rebuild on land. Electricity cables, plumbing and old, inefficient buildings could be redesigned.

DISADVANTAGES

Ocean conservation
We don't know the effect that floating cities will have on the ocean. However, we do know that even minor constructions in the sea can destroy marine life, so it's more than possible that floating industrial structures would also harm the ocean.

Supplying resources
It would be challenging to supply resources to an island that is floating in the middle of the ocean and would require extensive practice and research to ensure that people did not end up stranded and lacking food or drinking water.

Expensive
Constructing a state-of-the-art seafaring city would be very expensive. Exceptionally high start-up costs could well prove prohibitive, as investors are typically put off by projects requiring significant funding upfront.

Structure and stability
There are many things to think about when building a flexible structure, and engineers must innovate to create something that is structurally sound and will not break apart in the ocean, thereby risking the lives of all onboard.

Law and order
Building again comes with consequences. In the open ocean the societies will be unregulated, and the enforcement of new laws and legislation would have to be established for a safe community.

need to be submerged over 90 or so metres beneath the surface, which is prohibitively expensive. Additionally, the rigidity of this vast amount of steel would mean the ship would be dangerously vulnerable to being torn apart by waves hitting it from different directions.

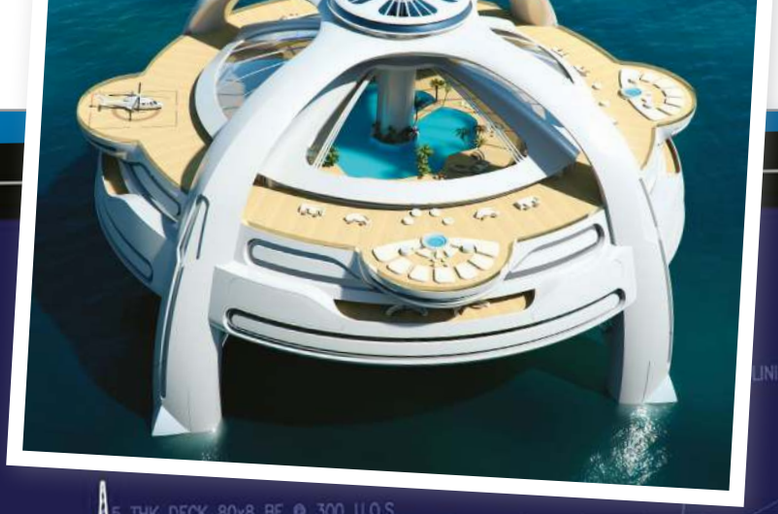
Once built, the next major challenge is ensuring the floating city is equipped to be completely self-sustainable out in the open ocean. If the structure remains near land then locating supplies wouldn't be too difficult. However, were it to move out into the ocean it would need to source everything from the sea or import goods and services from other countries.

At their most basic, humans need food, water and shelter to survive. An average person needs approximately three litres of water a day, and though these communities will be surrounded by water, the sea is too salty for us to drink – doing so would eventually be lethal. Instead, these floating communities will need to use onboard desalination plants, which remove the salt from the water supply using electrodialysis, distillation or reverse osmosis methods.

However, while the seawater may not be suitable for us, thanks to genetic modification technology it will be possible to cultivate salt-resistant plants. We could also grow our food using this expansive resource by building fish and shrimp farms in the open water, or we could cultivate extensive fields of edible algae.

The next big challenge to overcome is being able to generate electricity to power the homes and businesses on the city. Any project seeking to disconnect with the land-based electric grid needs to find another power source. Dominating the field in seasteading power technologies is Ocean Thermal Energy Conversion, a process that harnesses the natural temperature gradients of the ocean to generate power and thereby provide a sustainable fuel source.

At the forefront of the pioneering mission to colonise the sea is the non-profit organisation The Seasteading Institute, which is aiming to build a complete floating community by 2020. The proposed plans involve an array of hollow concrete reinforced platforms, built in 50-by-50-metre squares or pentagons that would attach to one another to build a network of branches. This freedom would mean that floating cities could be evacuated quickly by disconnecting from their neighbouring platform, meaning that populations would be able to move out of the path of a hurricane or away from dangerous weather conditions. It would also enable people to have greater



The Utopia yacht island

It might look like a Bond villain's lair, but individual seafaring apartment blocks like the Utopia concept could be a starting point for larger floating cities

Thrusters
At the bottom of each leg there is an azimuth thruster (a type of marine propeller that can be rotated to any horizontal angle) so the Utopia can be manoeuvred easily.

Observatory
65m above sea level, passengers could enjoy spectacular 360-degree views of their surroundings at the observation deck.

Living space
The Utopia design boasts enough space for a 'micronation', including residential, entertainment and service areas across its 11 decks.

"Between cyberspace and outer space lies the possibility of settling the oceans" **Peter Thiel**

Helipads
Designed with rich clientele in mind, the Utopia features multiple landing areas for residents' and guests' helicopters.

Docking ports
Visitors can arrive by boat at either the wet dock within the central spire or at one of the landing beaches on the legs.

Stability
Utopia's four-legged design ensures it will remain stable even in rough seas.

1	POWER GENERATION EQUIPMENT
2	MOORING EQUIPMENT
3	TANKAGE
4	AUX MACHINERY & SERVICES
5	AUX MACHINERY & SERVICES
6	CREW & SERVICES
7	ENTERTAINMENT DECK
8	ENTERTAINMENT DECK
9	VIP & GUEST DECK
10	OWNERS DECK
11	PROMENADE DECK
12	SERVICE DECK
13	OBSERVATORY
14	OBSERVATORY
15	LANDING BEACH
16	AZIMUTHING THRUSTERS
17	WET DOCK
18	WET DOCK ENTRANCE
19	HELICOPTER PAD
20	LIFEBOATS
21	RETRACTABLE CANOPY

LENGTH	100m
BREADTH	100m
DEPTH	15m

Yacht Island Design's Project Utopia is a 100-metre-wide, pod-shaped floating apartment block. Its 11 decks make up the equivalent volume of a cruise liner

yacht island DESIGN

Floating Island Project

Why this ambitious concept in French Polynesia is already making waves

"The dream of living in a floating utopian paradise may be just around the corner"

autonomy over their neighbourhood by voting with their house, as unsatisfied residents could move to another seastead in search of a better quality of life.

The ambitious proposal aims to build an entire city on these interlocking modular platforms that will include medical facilities, recreation grounds, schools, hotels and shopping centres. The project is backed by Paypal founder and billionaire Peter Thiel, a man determined to make this dream a reality.

Rather than head straight out into the open ocean, the first aim is to stay anchored close to a host country so that established resources can be utilised, and progress towards this has already been made.

Last year, a deal was signed between the French Polynesian government and the Seasteading Institute that committed both parties to agreeing to cooperate on the creation of a seazone. Mr Thiel has described the project as a long shot but one worth undertaking, commenting in an article that, "between cyberspace and outer space lies the possibility of settling the oceans."

The Institute's current mission is to finish its first concept build using 11 modules, each holding three-storey buildings that will offer housing, entertainment and office space for 225–300 full-time residents, as well as 50 hotel beds. The floating city will act as one giant laboratory to study sustainable science and put collaborative technology to the test.

Entrepreneurs who are keen to provide luxury homes that offer a solution for climate change refugees are also innovating in the field of seasteading. The Freedom Ship is set to be the largest ship in the world, using azimuth thruster marine propellers to power and steer the ocean-going colossus. Complete with an airport for private planes, it will allow residents to constantly cruise around the world, regularly stopping at ports to allow people to explore.

On the other end of the spectrum, there are smaller projects cropping up throughout the world that will seek to make floating homes accessible to everyone, one of which is Waterstudio, a company based in the Netherlands, which already lies below the sea. The country has seen an increasing number of people moving onto the water with houseboats to guarantee their homes stay dry, but in a vessel that small the passengers will feel even the slightest of turbulence. A standard houseboat would stand no chance out in the open ocean, but the Dutch company has brought the houseboat into the 21st century: founder Koen Olthuis has designed floating two-storey homes.

With one floor under the surface, the design mitigates the problems caused by gravity and weight distribution as it brings the centre of gravity downwards. Furthermore, without the need to dig deep pillars into the soft, marshy lands of the Netherlands, it is cheaper to build a houseboat than it is to erect a home on land.

Olthuis is developing his first city near The Hague on the western coast, incorporating social housing, floating islands and apartment buildings. This pioneer believes that a sustainable future lies beyond the waterfront, so could the future see prebuilt homes on standardised platforms being shipped out to an ever-expanding water city?

We can't predict exactly how humans will build into the ocean, but the challenges posed by a growing population and rising sea levels will test our ingenuity and engineering capabilities to their limits. The dream of living in a floating utopian paradise may be just around the corner, so kick back and ride the waves as humanity sails towards the development of new water-borne city states.

Modular platforms will allow neighbours to disconnect, travel alone and regroup miles away

The Seasteading Institute has suggested using solar panels for electricity

Q&A Joe Quirk

We speak to the co-founder and managing director of Blue Frontiers, a company working with the Seasteading Institute on their Floating Island project

Would you be able to explain some of the different technologies that will be used in floating cities?
Seasteads are a technology that aims to restore the ocean environment. Floating structures provide a home for sealife and thus increase ecosystems in the ocean. Seaweed farms absorb carbonic acid and thus help reduce ocean acidity. Floating solar panels – 'floatovoltaics' – are 20 per cent more efficient than solar panels on land. Blue Frontiers, a start-up company with a mission to build the first seasteads, plans underwater floors that will feature aquarium walls so students can see with their own eyes how floating neighbourhoods can restore the ocean environment. By integrating these and other blue technologies in one system, our Dutch engineers at Blue21 are committed to a complete paradigm shift, which they call cyclical metabolism. Their prototype is the sustainable Floating Pavilion in Rotterdam.

How do you see the future of seasteading? Will there be hundreds of cities like this, and where will they be?
We expect that when the first few seasteads set excellent examples for what the aquatic world can be, we will eventually see thousands of nanonations on the sea, unleashing the age of floating societies.

Could you describe why this innovation is so important? What are the driving factors to move into floating cities rather than remaining on land?
Two of the biggest problems in the world are sea level changes and the lack of start-up innovation in governance. Seasteads solve both. Floating islands will empower coastal communities to adjust organically to sea level change. Start-up societies on free seas will allow people to try new voluntary ways of governing themselves. As long as people can leave seasteads they don't like and choose those they prefer, they will engage a market process that will discover better ways of living together.

Where is the project at the moment? How far is the project into the 2020 target?
The start-up company Blue Frontiers, which will be building the first sustainable floating islands, has completed its environmental impact assessment, its economic impact assessment and has proposed the SeaZone, a legal innovation that incorporates the best practices that have been discovered in over 4,000 Special Economic Zones around the world. We hope French Polynesia leads the world in this innovation and then rapidly offers the seasteads to island nations around the world. Island nations didn't cause the problem with sea level rises, but they could offer an immediate solution.

Edible water bottles

Could these spheres of water replace plastic for good?

From bags and boxes to bottles and buckets, plastics are used in almost every aspect of daily life, yet if it's not properly recycled this material can endanger our environment. Scientists have estimated that before we reach the year 2050, the amount of plastic in the ocean will outweigh the fish living in it. We have banned microbeads, charged for plastic bags and encouraged everyone to recycle, but we are still producing huge amounts of plastic rubbish.

One company in the UK wants to tackle the problem head on by replacing water bottles with a natural, biodegradable alternative. The edible blobs, called Ooho!, are produced by Skipping Rocks Lab and hold liquid within a double membrane in a similar way in which an egg yolk keeps its spherical shape. The design is a smooth, clear container for liquids. They are formed from alginate, a molecule extracted from seaweed that has the special ability to turn water into gel in the presence of charged atoms like calcium.

To drink from them, you simply bite into the sphere and drink the liquid from inside. When you are finished with your refreshment the seaweed container can be eaten or discarded and will decompose in just a few weeks. They are available in different flavours, including orange, elderflower and blackcurrant. Keep your eye out for these innovative bubble-bottles around festivals and sporting events for on-the-go hydration.

Ooho! can biodegrade in four to six weeks, the same as a piece of fruit

A plastic-free future

In the UK 38.5 million plastic bottles are used every day, of which 15 million are not recycled and 700,000 are littered. Yet, though it may feel like we rely on this human-made substance, we can live without plastic, we just need to research and consider the alternatives. You could invest in a reusable bottle for your water or perhaps buy a Soda Stream to make your fizzy drinks rather than buying them contained within single-use plastic.

The rise of cardboard-based water packaging and public drinking taps means that one day we will be able to shift to a completely plastic-free lifestyle. Until then, why not try purchasing things in alternative packaging. For example, you can buy shampoo, creams, conditioners and other liquid products in soap-like bars.

Plastic pollution is a growing problem that we must tackle to protect our environment

MAKE YOUR OWN EDIBLE WATER BOTTLES

1 Dissolve one gram of sodium alginate into one cup (approximately 230–240 millilitres) of drinking water and use a whisk to blend them together thoroughly. Once fully dissolved, with no lumps, let the mixture sit for 15 minutes or until there are no more air bubbles left.

2 Dissolve five grams of calcium lactate into four cups (approximately 920–960 millilitres) of water in a different bowl and whisk until it is completely dissolved.

3 Scoop some of the sodium alginate solution into a ladle or a large spoon and gently place it into the bowl of dissolved calcium lactate. A sphere will start to form instantly. Repeat the process to create more spheres sitting in the bowl, making sure each is fully covered in solution.

4 Gently stir the solution – being careful not to pop any of the spheres – for several minutes until they have completely formed into ball shapes.

5 Take a slotted spoon and remove the water balls from the bowl before placing them into a new bowl of fresh water to stop the chemical reaction.

"We could replace plastic bottles with a natural, biodegradable alternative"

Follow the experiment on our website **howitworksdaily.com**

Inside the new iMac Pro

Discover the hi-tech wizardry and cutting-edge components powering Apple's advanced desktop

For creative users, Apple's Mac computers have long been the first choice thanks to their powerful software and hardware combinations. These users, who typically work in the film, music and photography industries (to name a few) need powerful machines for these complex and demanding tasks. Apple's response was its 'Pro' line, and now there's a new, powerful plaything for them to try – the iMac Pro, with Apple claiming it's the most powerful Mac ever.

This Mac packs in a 5K display, up to 18 cores in its built-in processors, up to 128GB of RAM, a massive amount of fast storage and more high-speed connectivity than any other previous Mac. It's got four Thunderbolt 3 ports, four USB 3 ports, plus ports for an SD card, ethernet cable and more.

Inside, you can store up to 4TB of files and data on solid-state drives that are much faster than standard hard drives. Oh, and did we mention that it comes in a sleek black design?

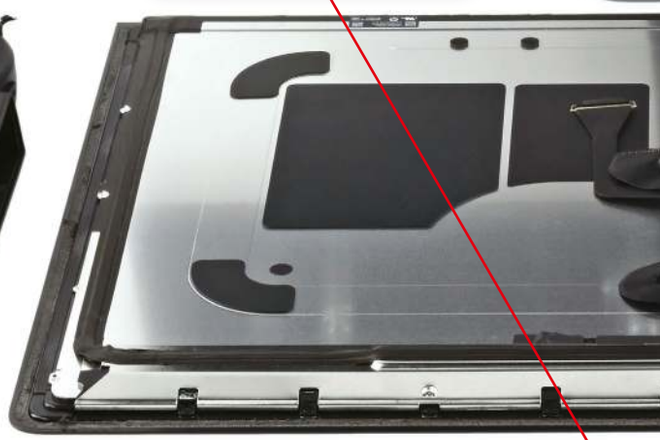
All of these impressive numbers and statistics add up to the most powerful Mac ever made. The iMac Pro outstrips most other Macs by up to 12 times when it comes to performing specific tasks, and that means that those creative users can get more done more quickly than ever before. The downside? This much power doesn't come cheap. The iMac Pro starts at £4,899/$4,999, and with every bell and whistle installed it could cost up to £12,428/$13,348. Let's find out exactly what's inside the iMac Pro to make it so expensive...

Behind the screen

What tech powers the most powerful iMac yet?

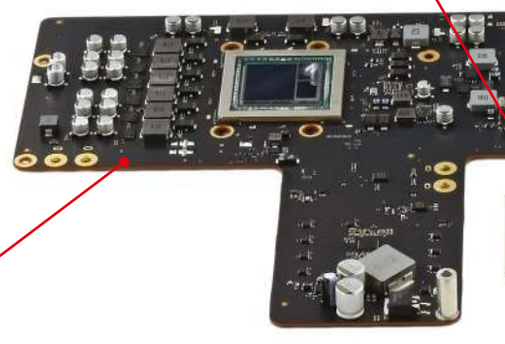
Dual-fan cooler
These fans offer 80 per cent increased cooling capacity and are asymmetrical to make them spin more quietly.

Dual-SSDs
These two tiny cards are where all of the files and data are stored, and because they're not hard drives they're superfast.



RAM
These memory units each hold 8GB of RAM but can be upgraded for a total of 128GB if you want more power.

The Pro is a machine designed with professional creative users in mind, such as 3D designers



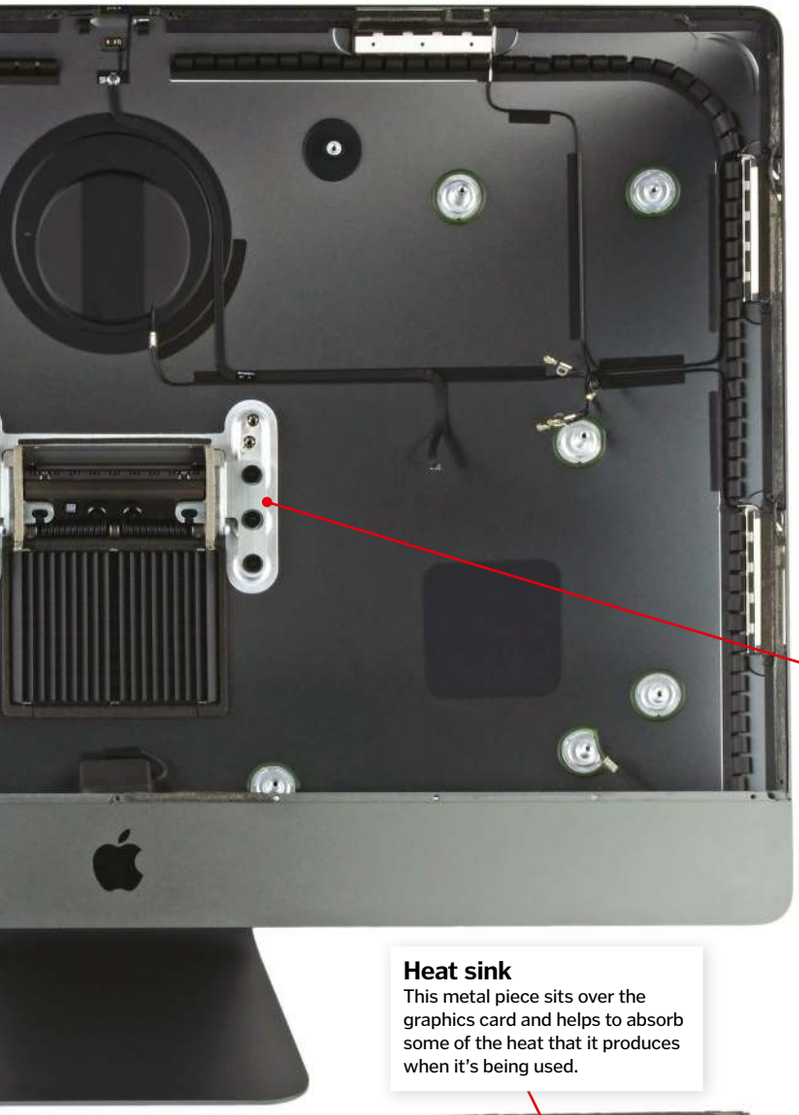
Main logic board
This is where all the important chips are kept for the iMac Pro, including the processor and integrated graphics card.

What is Turbo Boost?

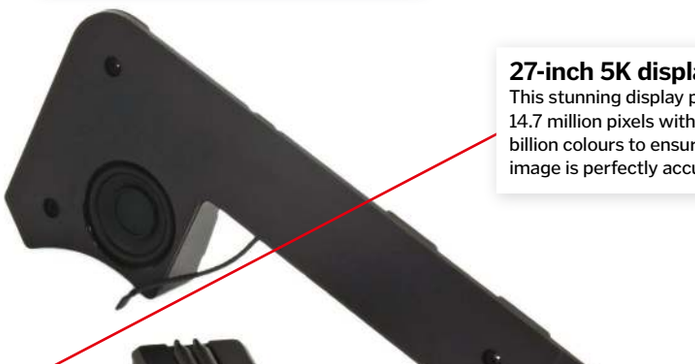
The ten-core, 3.0GHz Intel Xeon W model of the iMac Pro also mentions that the processor has the ability to 'Turbo Boost' up to 4.5GHz. This is a term invented by Intel, the processor's manufacturer, but what does it actually mean?

Turbo Boost is a built-in system that allows the processor to temporarily run faster than it's normal limits to give improved performance. Users cannot control when this happens as it depends on the workload and operating environment of the computer.

The processor will sometimes 'over-clock' (the term used for this phenomenon) when the computer is being pushed to complete several complex tasks at once, and this will often kick the fans into overdrive as the processor gets hotter due to the increased workload. To avoid any damage this process won't last long.



Spring-loaded hinge
This mechanism holds the iMac in place at any angle the user wants – simply tip it forward or back and the hinge will hold it.



27-inch 5K display
This stunning display packs in 14.7 million pixels with 1 billion colours to ensure every image is perfectly accurate.

Heat sink
This metal piece sits over the graphics card and helps to absorb some of the heat that it produces when it's being used.

Stereo speakers
These two similar pieces are where the iMac Pro's audio is produced, giving a rounded sound with deep bass.

Power supply
This large component takes the power from the wall socket and converts it to power the iMac Pro's hardware.

How paper is made

The chemistry and engineering involved in transforming pines into pages

From our favourite books or magazines to the pages of our notepads or sketchbooks, we have used paper to help share ideas and information since the process was invented in China in the second century CE. Papermaking is a craft that has remained fundamentally unchanged throughout the years, but modern technology has dramatically increased the quality and efficiency.

All paper products, like the pages of this magazine, for example, start out life as a tree. Its bark is removed and the remaining wood is chipped, mashed into a pulp and processed by machines to make it smooth and durable.

Before the papermaking process was industrialised our ancestors would have used bone, bamboo or papyrus to jot down their ideas or keep records. The first handmade paper from wood was creating by diluting the pulp into a soup of cellulose fibres and then sieving the material over a mesh-like screen, which encouraged the fibres to interweave. The resulting mush was then pressed to remove water, leaving a matted sheet.

It wasn't until the 19th century – when the steam-driven papermaking machine was invented – that people were able to produce paper on a large scale. With the fountain pen and the pencil invented around a similar period, wood paper became commonplace, revolutionising economies and societies around the world. Printed academic texts, newspapers and books all became available before the closing of the century.

The industry is now dominated by North America, Europe and east Asia, with mills around the world producing some 400 million tons of paper every year. The machines involved in the process perform largely the same steps as traditional papermaking but have made the process faster, consistent and more efficient. They have four distinct sections for forming, pressing, drying and calendering.

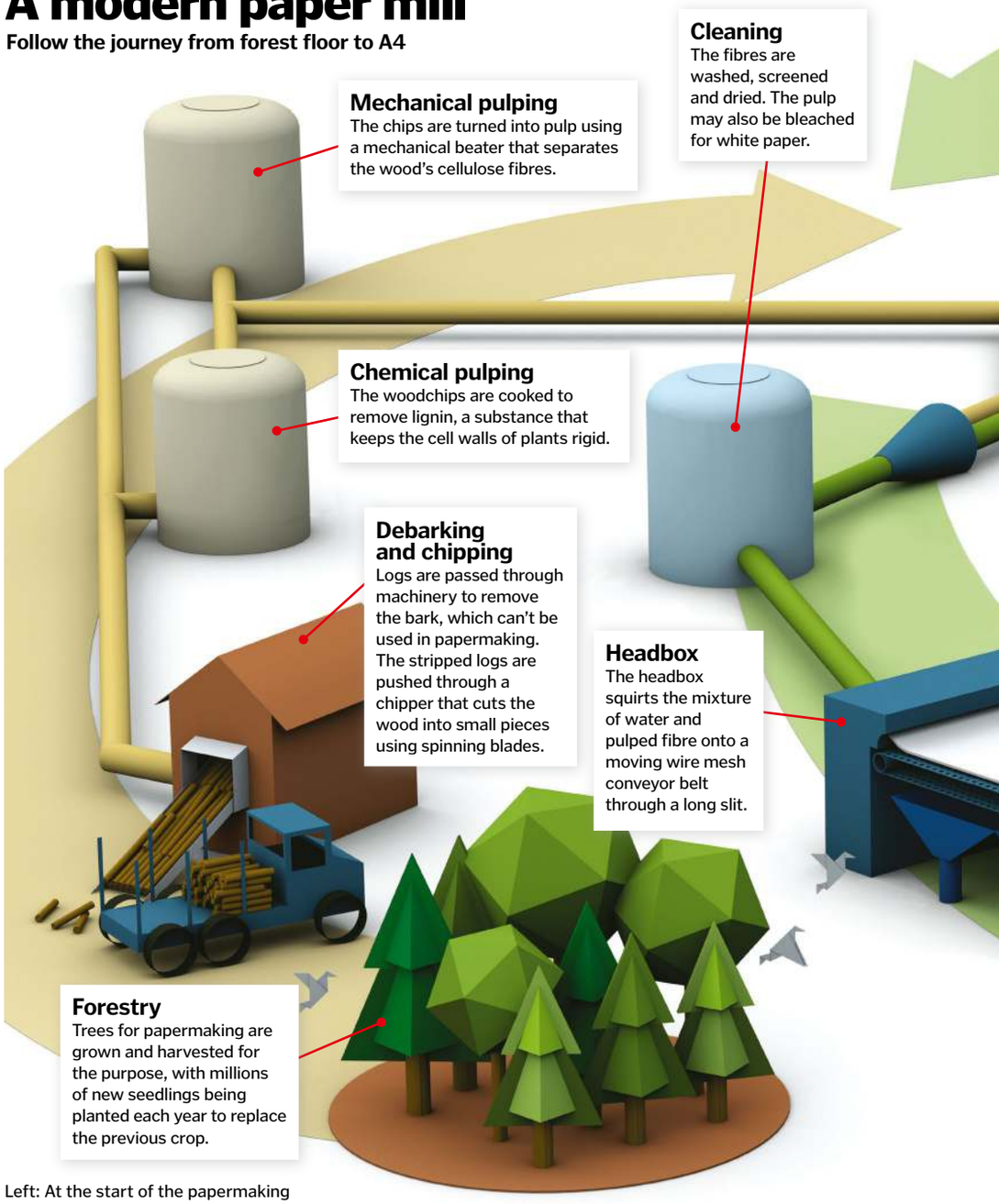
The most common devices used today are Fourdrinier machines, which produce paper at an incredible rate of over 60 kilometres of sheets per hour. With these hi-tech methods we produce more than enough paper to stock our stationary cupboards, offices and schools.

Above: Paper is pulled through a series of cylinders during the process to help dry and smooth the product

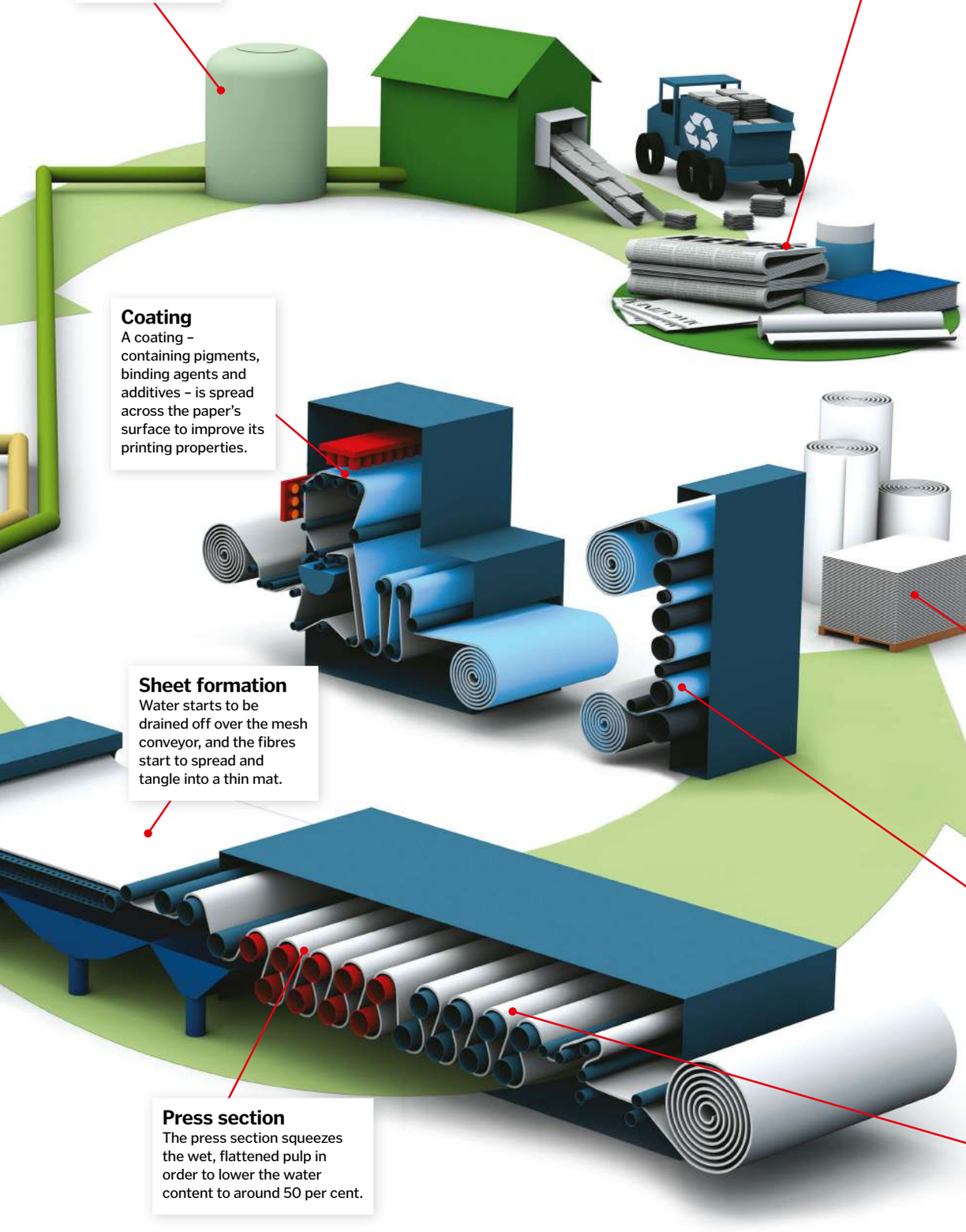
Left: At the start of the papermaking process trees are shredded into woodchips before being pulped

A modern paper mill

Follow the journey from forest floor to A4



"All paper products, like the pages of this magazine, for example, start out life as a tree"



De-inked
The adhesives and ink are removed using a floatation process before joining the cycle at the headbox.

Used paper
Paper products can be recycled ready to be turned back into new sheets. First, the used paper is dissolved into a pulp.

Coating
A coating – containing pigments, binding agents and additives – is spread across the paper's surface to improve its printing properties.

Sheet formation
Water starts to be drained off over the mesh conveyor, and the fibres start to spread and tangle into a thin mat.

Finishing
The giant paper sheets are wound onto a reel before being cut into the sizes you see available on the shelves.

Calendering
The paper is put through a set of calender rollers that act as an iron to give the paper its smooth and glossy texture.

Press section
The press section squeezes the wet, flattened pulp in order to lower the water content to around 50 per cent.

Drying
The web of paper weaves between a series of cast iron cylinders, heated to 100˚C or more to help speed up the drying process.

FIVE FANTASTIC FACTS ABOUT PAPER

1 Supply & demand
Approximately 80 million tons of paper is used in the US every year, from milk cartons and cardboard boxes to office supplies and school textbooks.

2 One tree goes a very long way
Most paper is made from pine trees. A single pine can produce more than 80,000 sheets of photocopier paper.

3 Paper art
The art of paper-folding is called origami, which spread in Japan during the 17th century.

4 Recycling industry
Approximately two-thirds of the paper we use today gets recycled. Every ton of paper that gets recycled, rather than making it from scratch, saves over 31,000 litres of water.

5 Grades and types
The differences in grades and types of paper are determined by the type of fibre, the degree of beating or refining of the pulp, the addition of materials, the weight and the treatments applied after the paper's formation.

Pumpjacks provide access to oil reserves that are buried deep below the surface

Oil pumpjacks

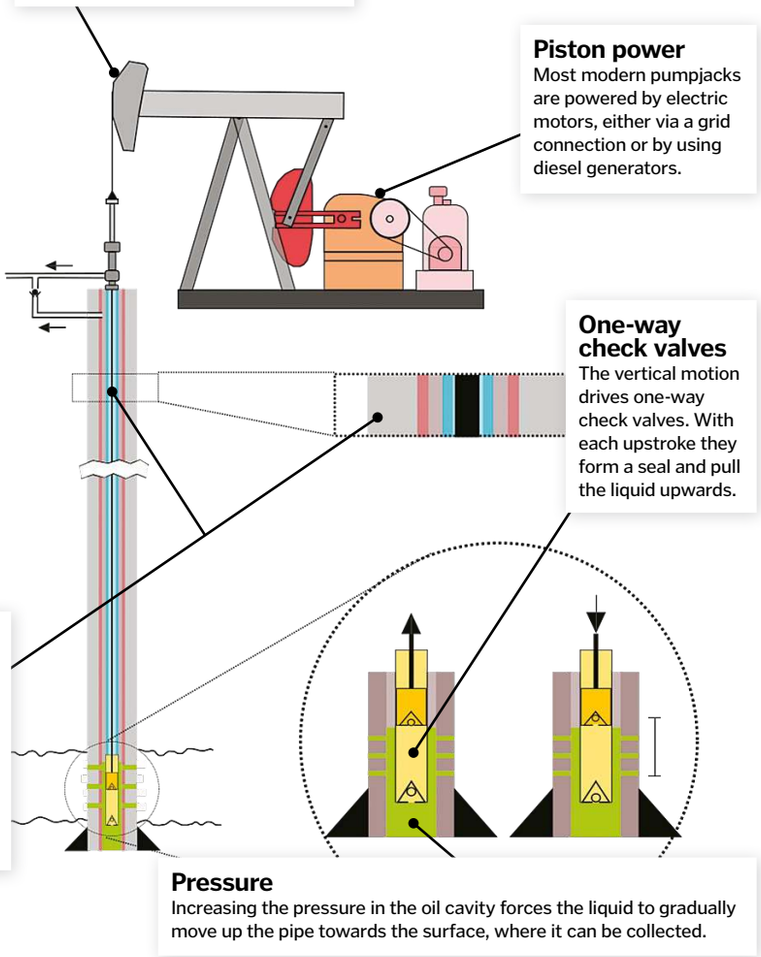
The machinery we use to bring this vital natural resource to the surface

If you've ever been to Texas you may have seen the characteristic metal hammer head of a pumpjack bobbing up and down in the oil fields. These machines are used to manually extract oil from underground wells when there isn't enough pressure below for the liquid to naturally flow towards the surface.

Pumpjacks generate artificial lift by increasing the pressure in the well, which forces the oil up the borehole. These efficient machines can pump around 20 times a minute, bringing with them between five and 40 litres of liquid with each stroke depending on their size.

Extracting oil

How does a pumpjack help bring buried liquid to the surface?



Bobbing motion
The head of the pumpjack bobs up and down, moving the rod extending into the well up and down too.

Piston power
Most modern pumpjacks are powered by electric motors, either via a grid connection or by using diesel generators.

One-way check valves
The vertical motion drives one-way check valves. With each upstroke they form a seal and pull the liquid upwards.

Borehole
The boreholes to oil wells are strengthened by lining them with steel piping and cement. This also protects against pressure fluctuations at different depths, which could affect the pumping process.

Pressure
Increasing the pressure in the oil cavity forces the liquid to gradually move up the pipe towards the surface, where it can be collected.

What is defragmentation?

How does this process improve the efficiency of your data storage?

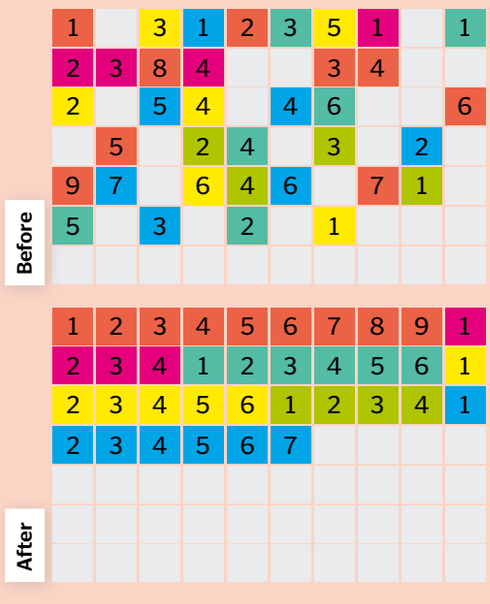
If your computer has a hard disc drive your data is stored in ordered, sequential blocks so the information is initially kept close together. However, once the disc fills up and you delete files, the slots you free up may be spread over multiple locations on the disc. This means that new data is divided up and stored in separated blocks rather than all together. This can slow down your computer when it accesses this fragmented data, because the drive head will have to work overtime to visit each part of the file across the disc.

When you start a defragmenting or 'defragging' program, your computer reorganises all of the blocks back into their rightful order, giving the drive head much less work as it doesn't have to run back and forth across the disc. It also means that a larger amount of space is kept free on the hard drive as the files are more compacted.

Most operating systems will automatically defragment your drive on a regular basis, but if you're computer is running slowly it may help to defrag it manually.

The disc (called a platter) within your hard drive stores information in binary form, and the arm mechanism with a read/write head moves across it to read or store data

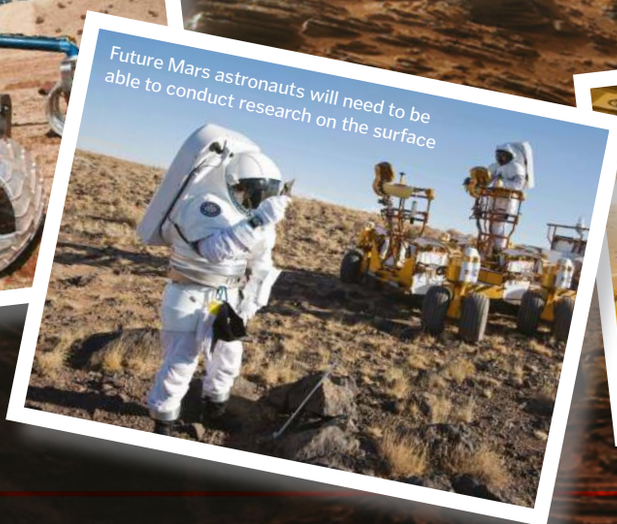
Defragging a computer can be visualised as squares on the screen – this image shows a before and after representation of a defragmented hard drive



MAR simulatio

Words by **Jonny O'Callaghan**

NASA puts its rovers to the test here on Earth to prepare them for Mars



Future Mars astronauts will need to be able to conduct research on the surface

The Airbus Defence and Space's Mars Yard in Stevenage, UK, is used to test out rovers

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How we're preparing for humanity's greatest challenge yet – living on Mars

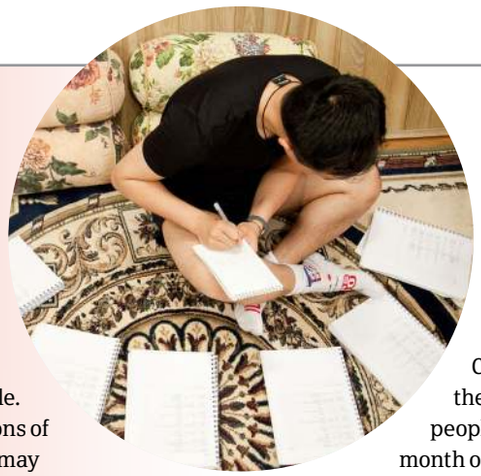
There is no shortage of dreamers with their eyes on Mars. From SpaceX CEO Elon Musk's proposal to settle a million people there within a century, to NASA's more modest attempts to land crews on the surface and return to Earth in the 2030s, the Red Planet is the 21st century's promised land. But while getting humans there will be difficult enough, surviving on the surface will be no less taxing. That's why for two decades scientists have been practising for future Mars missions by conducting simulated missions right here on Earth, ensuring we're ready for some of the challenges that will face us.

While we may one day colonise Mars, our initial forays will be lengthy return trips that push the limits of the human body. Astronauts will have to cope with a travel time of up to eight months in each direction, locked away on a spacecraft drifting through space. Owing to the orbits of our planets, which only align for a trip between the two roughly every 26 months, they'll also need to spend months on the surface conducting research before they can even consider coming home. Astronauts will need to be physically prepared for prolonged conditions in lower gravity and, just as importantly, psychologically ready for the intense isolation such missions will entail.

Mars and Earth, at first glance, could not seem more different. Our own planet contains everything we need to survive, from a breathable atmosphere to food aplenty and, crucially, water. Mars, on the other hand, is deadly. Here, a thin atmosphere does little to protect the surface from harsh levels of radiation. The poisonous atmosphere composed almost entirely of carbon dioxide does little to entice visitors, and a seemingly barren surface, devoid of any obvious liquid water, leaves the planet without one of life's greatest necessities. Yet Mars is also the closest planet to Earth we could feasibly explore with our own two feet. Venus, despite being slightly closer at times, hides a hellish landscape under its thick atmosphere where sulphuric acid rains down and temperatures are hot enough to melt lead.

"Simulation missions will prepare us for the challenges of Mars"

The proposed Mars Science City in the UAE will be the most ambitious Mars simulation yet



The Mars 500 crew had to monitor their physical and mental well-being

Mercury, our Solar System's other rocky planet, is so close to the Sun that travelling there is extremely difficult – and even if you did, the lack of an atmosphere renders its surface all but inhospitable. While some of the icy moons of the gas giants further out may look appealing, they are places only our descendants will contemplate visiting. Mars, upon closer inspection, starts to look quite enticing.

Thus it has become the focus of many of our near-future exploration proposals, a rocky world that may well see humans walk its surface in the coming decades. While our two planets are not much alike, we do know a lot about the Red Planet thanks to numerous orbiters and rovers that have been sent there. As such, we have been able to conduct simulation missions right here on Earth to prepare astronauts for what it might be like on Mars.

Over the last two decades numerous such missions have taken place. The goal of these has been mostly to house small crews inside habitats on Earth. Here, so-called 'Marstronauts' practise Red Planet missions, living in isolation for up to a year at a time with limited communications with an outside team to simulate mission control on Earth. These habitats contain everything they need to survive, including facilities to grow plants, exercise machines, kitchens and bathrooms. One of the earliest attempts was the Flashline Mars Arctic Research Station (FMARS), established by the Mars Society in Nunavut, Canada in 2000. Since then, 14 crews of about six people each have spent a month or so in the station at a time, practising techniques such as aerial surveys that might be useful on future missions. The Mars Society also runs the Mars Desert Research Station (MDRS) in Utah, US, which houses crews for a couple of weeks. Here, the crews have conducted experiments that include practising techniques for detecting life on Mars.

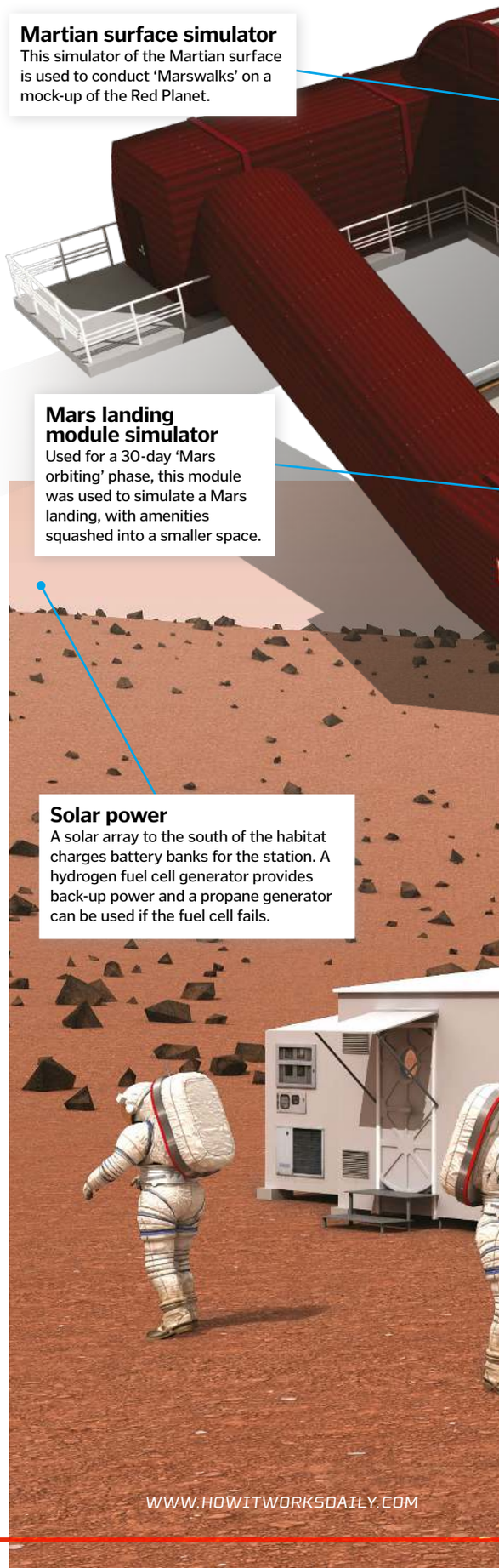
The goals of these projects and others is to provide an environment that is as close to Mars as possible, making areas like the deserts of Utah particularly useful. While we can't replicate the conditions exactly, we can get pretty close. At some facilities astronauts even go outside on practice 'Marswalks', seeing how they would cope exploring the surface of Mars, where, despite gravity being about one-third that of Earth, conditions can seem surprisingly Earth-like at times.

Many of the missions not only test out new technologies but also the psychological aspect of living in isolation for so long. In June 2010, a joint Russian-European-Chinese mission called Mars 500 took place, which housed a crew of six inside a mock spacecraft for 520 days. This was intended to simulate the time it would take to

The crew outside HI-SEAS perform a mock Marswalk

Inside Mars 500

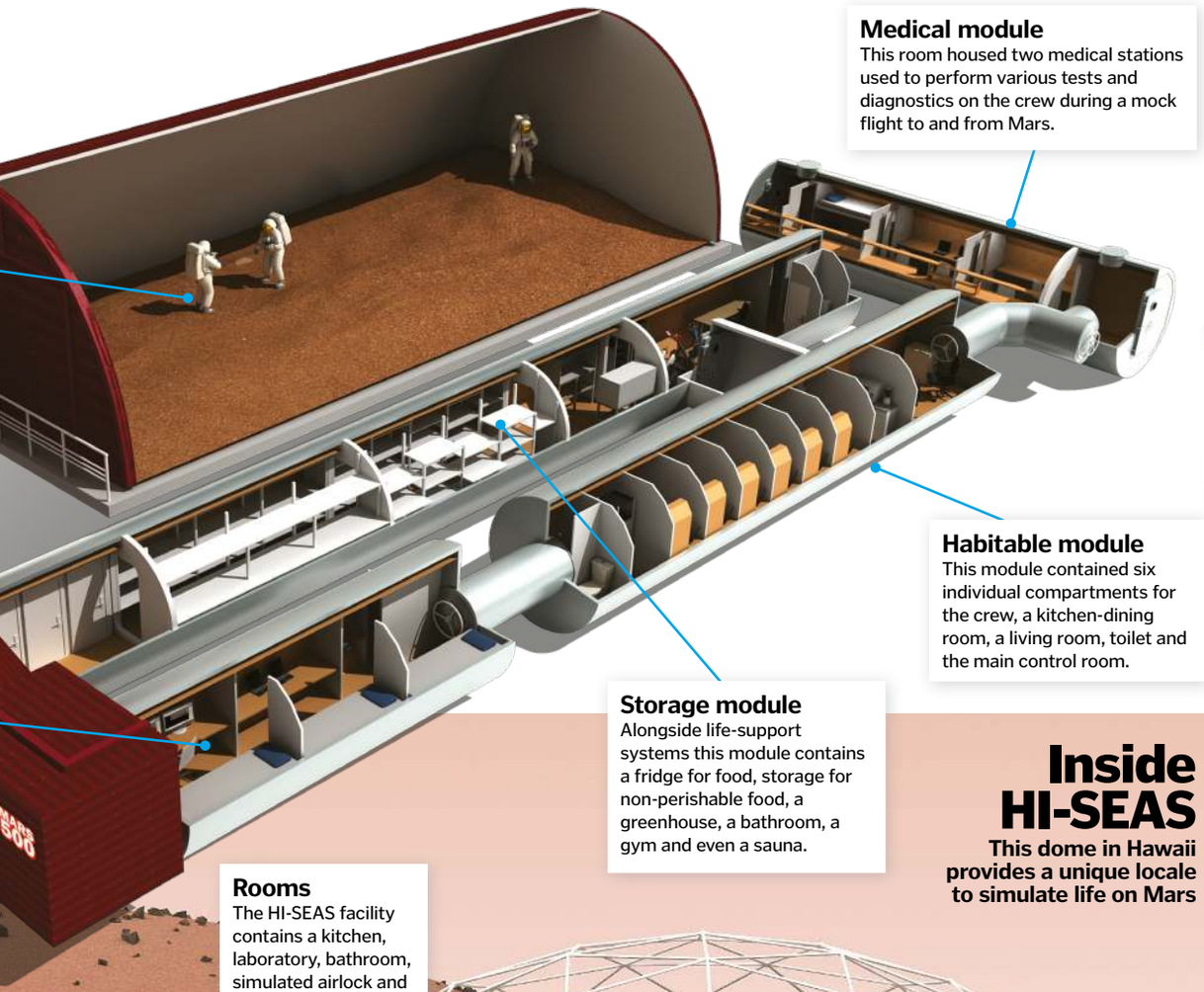
How this facility in Moscow helps us prepare for trips to the Red Planet



Martian surface simulator
This simulator of the Martian surface is used to conduct 'Marswalks' on a mock-up of the Red Planet.

Mars landing module simulator
Used for a 30-day 'Mars orbiting' phase, this module was used to simulate a Mars landing, with amenities squashed into a smaller space.

Solar power
A solar array to the south of the habitat charges battery banks for the station. A hydrogen fuel cell generator provides back-up power and a propane generator can be used if the fuel cell fails.

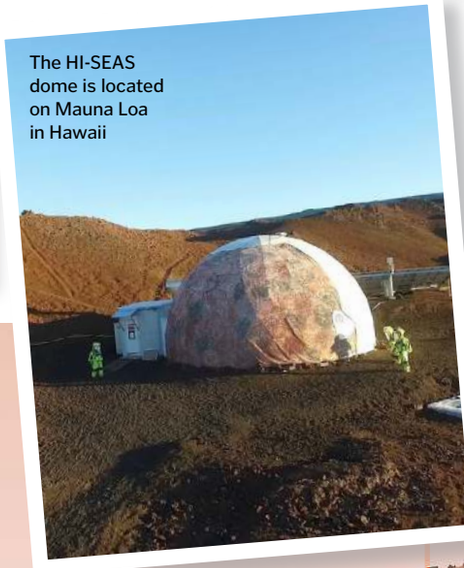


Medical module
This room housed two medical stations used to perform various tests and diagnostics on the crew during a mock flight to and from Mars.

Habitable module
This module contained six individual compartments for the crew, a kitchen-dining room, a living room, toilet and the main control room.

Storage module
Alongside life-support systems this module contains a fridge for food, storage for non-perishable food, a greenhouse, a bathroom, a gym and even a sauna.

The Mars 500 crew shortly after leaving isolation



The HI-SEAS dome is located on Mauna Loa in Hawaii

Inside HI-SEAS

This dome in Hawaii provides a unique locale to simulate life on Mars

Rooms
The HI-SEAS facility contains a kitchen, laboratory, bathroom, simulated airlock and six bedrooms for the crew over two floors.

The dome
A crew of six live inside the 11m-diameter dome, which has a habitable area of about 110sq m.

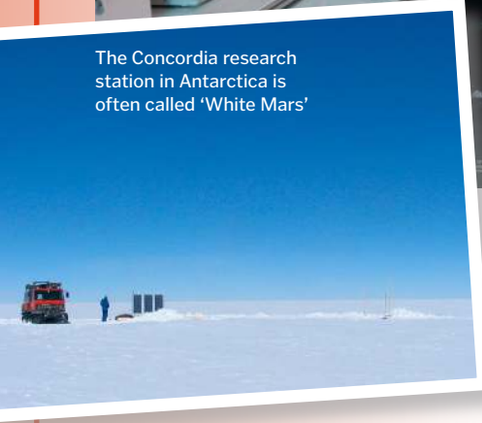
Delay
A 20-minute delay in communications with 'Earth' helps add to the realism of being on Mars.

Marswalks
The crew exits through the mock airlock to perform simulated excursions outside the dome.

"At some facilities astronauts even go outside on practice 'Marswalks'"

Right: NASA's deep-sea NEEMO facility helps prepare for life in isolation

NASA's HERA mission involved testing sleep reduction in a mock-up spacecraft



The Concordia research station in Antarctica is often called 'White Mars'

travel to Mars and back, with the crew also performing a mock-up 'Mars landing' when they 'arrived' at the planet during the mission.

NASA has also been testing the limits of human psychology, having conducted a year-long mission on the International Space Station (ISS) from March 2015 to March 2016. American astronaut Scott Kelly, in partnership with Russian cosmonaut Mikhail Kornienko, spent twice as long on the orbiting laboratory as typical US missions in order to see how they coped with the stresses of prolonged spaceflight.

However, it's not just humans that have to prepare for Mars. The European Space Agency (ESA), have Mars Yards here on Earth, where they can test out rovers on simulated Martian terrain to see how they will cope. ESA is planning to send a rover called ExoMars to the Red Planet in 2020, so they are currently running it through various tests here on Earth to see if it can handle steering over or around rocks. They also test out its instruments to make sure they'll be able to analyse the surface of a planet at least 54.6 million kilometres away.

Over in Hawaii, there's another human Mars analogue mission called HI-SEAS (Hawaii Space Exploration Analog and Simulation) run by Cornell University and the University of Hawaii at Manoa in partnership with NASA. This facility is shaped like a giant dome, which might be closer in appearance to future Mars habitats – a dome or spherical shape holds up much better under the lower pressure on Mars than a rigid square or rectangle. Teams at HI-SEAS live in confined conditions and have to contend with a 20-minute communication delay, just as future Marstronauts would expect, among other challenges during their mission.

At the Concordia research station in Antarctica, there's a different sort of Mars simulation experiment taking place, where up to 16 people live very much in isolation for up to a year at a time. This French-Italian facility, run by the ESA, endures four months of continual darkness every year, while its freezing conditions have earned it the name 'White Mars'. The endless dark, white environment provides an excellent analogue for what it might be like to live in isolation on the Red Planet.

All of these projects highlight one thing: there is a continued clamour for Mars, and the desire to send humans to our neighbouring planet is only growing. With new rockets and spacecraft being developed that make that dream more of a reality, research from Mars simulation missions could prove vital in ensuring humans are prepared for the isolation that initial missions will require. While we may one day have vast colonies there housing thousands of people, initial missions will be lonely affairs, with crews of a handful of people spending months on a barren planet far from Earth. To prepare for those missions, well, there's no place like home.

Mars Science City

In 2017, the United Arab Emirates (UAE) announced that it wanted to build a city on Mars within a century – by 2117. In preparation for doing so, it is constructing a $140-million (£100-million) test on Earth called the Mars Science City.

The huge complex, made of connecting domes, will span nearly 177,000 square metres. It will allow scientists to conduct experiments in the desert near Dubai for future explorers on Mars. This will include housing a giant greenhouse to hone agricultural techniques and ensuring the 3D-printed structure blocks solar radiation. There will also be a museum where visitors can learn more about space exploration.

Designed by Danish architecture firm, Bjarke Ingels Group, the complex will be much bigger than previous Mars simulations. A team will live inside the habitat for a year, although the UAE hasn't yet released all its plans. If successful, the Mars Science City could be a major step towards preparing for life on the Red Planet.

The Mars Science City in the UAE desert will be a large-scale simulation of a Red Planet habitat

The project will be used for scientific research, but will also provide education for the public

The complex will include a greenhouse to practise growing plants under LEDs

MAKING IT ON MARS

We'll need more than food and shelter to survive off-planet. Danish architecture firm Bjarke Ingels Group have identified eight major factors will be vital for future Mars missions – the graphic below illustrates how they are all connected

Recreation
All work and no play makes Jack a dull boy. Future astronauts or citizens on Mars will need some form of entertainment, with proposals including cinemas or even rock climbing.

Nature
Astronauts will need to perfect growing techniques in order to be as self-sustainable as possible on Mars. This includes finding ways to grow plants in lower light conditions.

Food
Regular cargo missions from Earth might be in short supply while on Mars, not to mention very expensive. Astronauts will need to be capable of growing their own food.

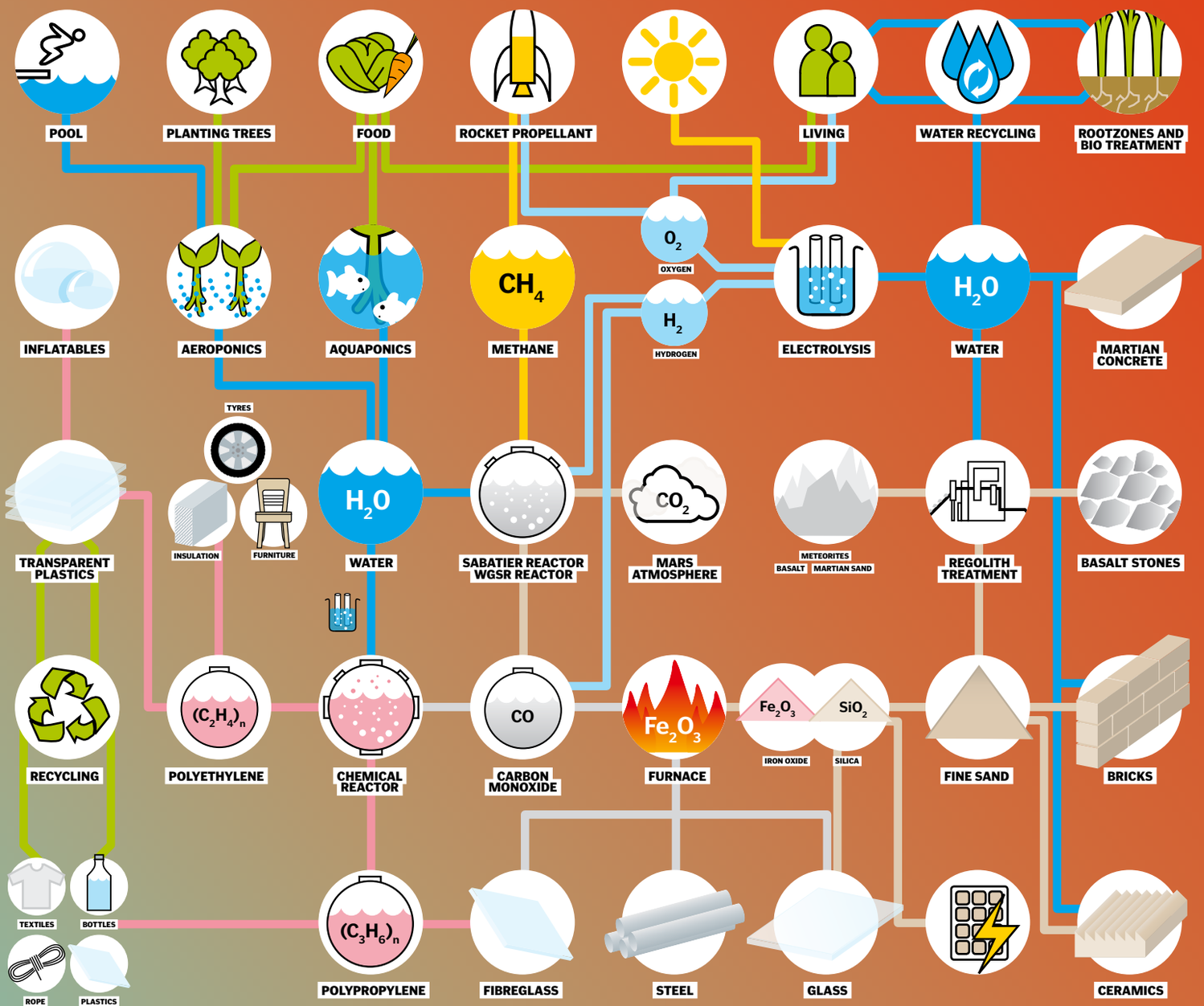
Transport
Mars missions will need to find ways to make fuel, possibly by turning the abundant quantities of carbon dioxide into methane, so they can leave the surface when necessary.

Energy
The sunlight that Mars receives is less than half as intense as it is on Earth, meaning that solar panels will need to make better use of the available energy to fully sustain a colony.

Climate
Humans cannot survive out in the open on Mars, so they'll need to live inside pressurised habitats that can mimic the pressure, temperatures and climate found back on Earth.

Water
Mars has water locked away in ice at its poles and under its surface. It's hoped that we might be able to use this for future missions, alongside efficient water recycling systems.

Waste
Any missions to Mars will need to ensure they do not contaminate the surface with Earth-based microbes, which could lead to a false detection of life in the future.



Types of asteroid

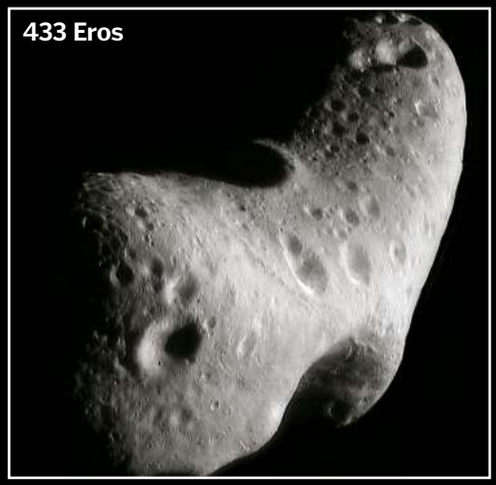
The differences between four main categories of these space rocks explained

253 Mathilde

C-TYPE
Carbonaceous

These asteroids are numerous yet difficult to find – they are so dark due to their carbon-black surfaces that even the largest require a telescope to detect them. They consist mostly of clay and silicate rocks and account for more than 75 per cent of all asteroids. Most of these ancient space rocks orbit in the outermost regions of the asteroid belt furthest from the Sun.

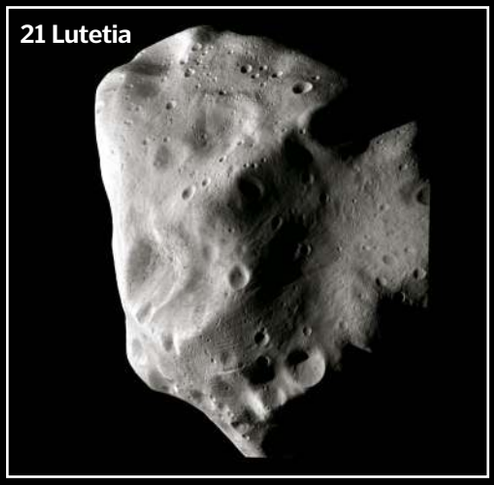
433 Eros



S-TYPE
Stony

This class of asteroids orbit the inner asteroid belt and are primarily composed of stony materials, metallic nickel-iron as well as iron and magnesium silicates. S-types are the second most common asteroids and are also among the brightest – some large examples, such as 7 Iris, can be spotted with binoculars.

21 Lutetia



M-TYPE
Metallic

M-types are pure metal or mixtures of metal and small amounts of stone and have originated from the cores of planetary bodies that have been broken apart by impacts. Most are metallic, comprising largely of nickel-iron, and they are found in the middle region of the asteroid belt.

4 Vesta

V-TYPE
Vestoid

V-types are those that have similar surface properties to 4 Vesta, which is one of the largest asteroids in the Solar System. This group are not so different in composition to the more common S-type: they are also made from stony iron and chondrites, but they contain higher levels of silicon-aluminium oxides called pyroxenes. They are a reddish colour and have a basaltic volcanic crust.

NASA's interstellar mission

Why the US space agency has started planning a mission 100 years in advance with technology that doesn't exist yet

Alpha Centauri is the closest star system to our own, consisting of Alpha Centauri A and B (which form a binary system) and C (a small red dwarf orbiting the other two). The system has been a mission target for decades, although the discovery of a potentially habitable exoplanet has boosted the drive to explore the region.

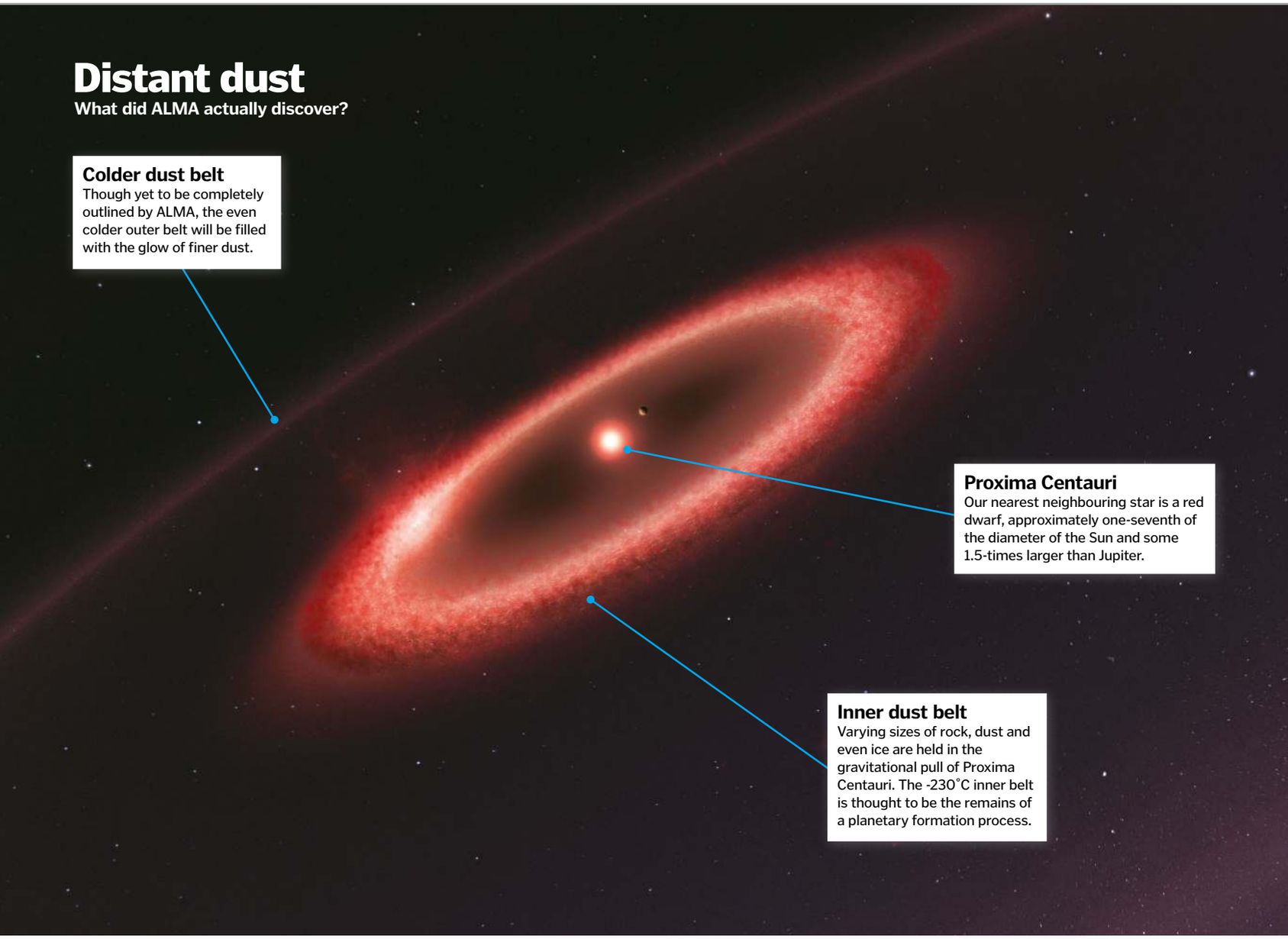
However, there are two big problems: the technology for the 4.37-lightyear voyage doesn't exist yet, and the distance to cover is so great that even the children of the researchers working on the project will probably not live long enough to see the work to completion. Even so, that hasn't deterred NASA, who are relying on technology advancing far enough in time to launch an interstellar robotic space probe in 2069.

The challenge is to produce equipment capable of moving fast across long distances. Even one of the fastest probes, New Horizons, which travels at over 58,000 kilometres per hour, would take about 78,000 years to get to Alpha Centauri. NASA want to get this travel time down to decades rather than millenia. To reach our neighbouring stars in around 44 years, NASA aims to develop propulsion methods to send a probe speeding towards the stars at ten per cent the speed of light. Several ways of achieving this have been proposed, from small probes with solar sails powered by lasers to colliding matter and antimatter.

An artist's impression of the lightsail spacecraft that may be developed to explore the exoplanets in the Centauri system

Distant dust

What did ALMA actually discover?



Cold dust

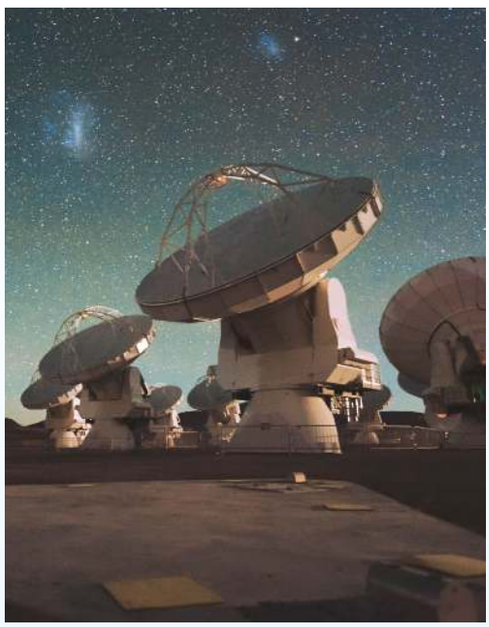
The discovery of a neighbouring dust belt could reveal unknown planets

Circling around our closest star, Proxima Centauri, a mere four or so lightyears away, is a previously undetected dust belt. Both an inner and a finer outer dust belt were detected around our interstellar neighbour by the Atacama Large Millimeter/submillimeter Array (ALMA) observatory in Chile.

Dust belts are the accumulation of rock ranging from millimetre-wide grains to kilometre-sized asteroids. What they all have in common is their failure to conglomerate (merge together) to form larger planetary bodies. The closest examples of our own such belts are the main asteroid belt between Mars and Jupiter and the outer-reaching Kuiper belt past the dwarf planet Pluto.

The reason these belts are labelled as 'cold dust' is due to the lack of heat they receive from their parent star, which is directly related to their distance apart. Extending around a few hundred million kilometres from Proxima Centauri, the inner ring is around -230 degrees Celsius. The finer dust belt lies about ten-times further out and is predicted to be much cooler.

By studying other solar systems we are able to better understand different complex planetary systems, providing clues as to how the universe developed. Proxima Centauri has been a focal point in the hunt for exoplanets. In 2016 the discovery of exoplanet Proxima b orbiting the star revealed a planet with the potential to sustain life in a similar way to that of Earth.



The ALMA telescope is made up of 66 antennas, and is use to study light from some of the coldest objects in the universe

HOW IT WORKS

THE 149 MOONS OF OUR SOLAR SYSTEM

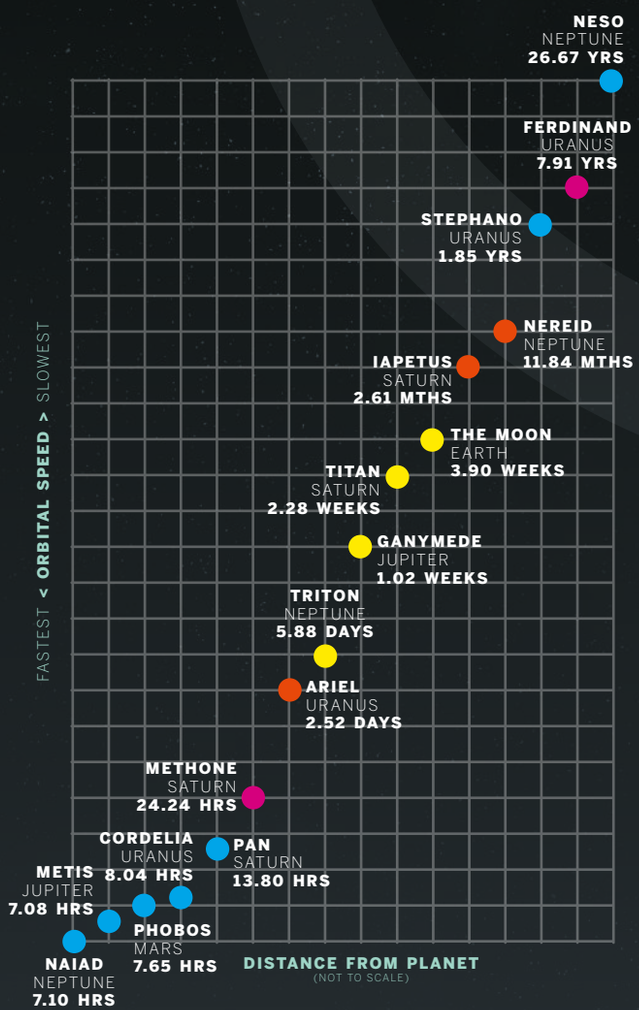
How do all of the moons in the Solar System compare to one another? Find out in this guide to every single confirmed natural satellite

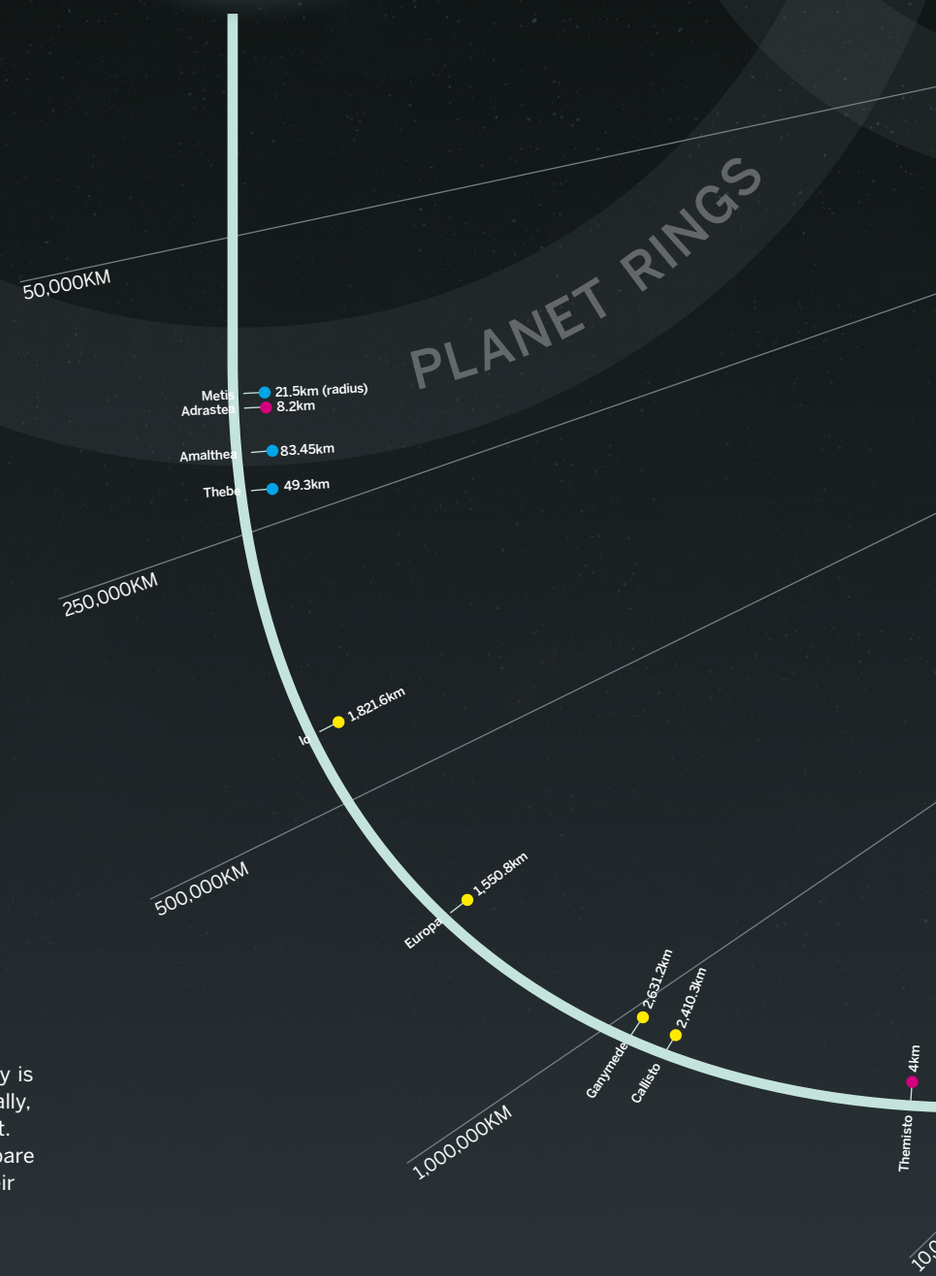
MOON RADIUS CLASSIFICATION

- > 1,000km
- 101–1,000km
- 11–100km
- < 10km

JUPITER
53

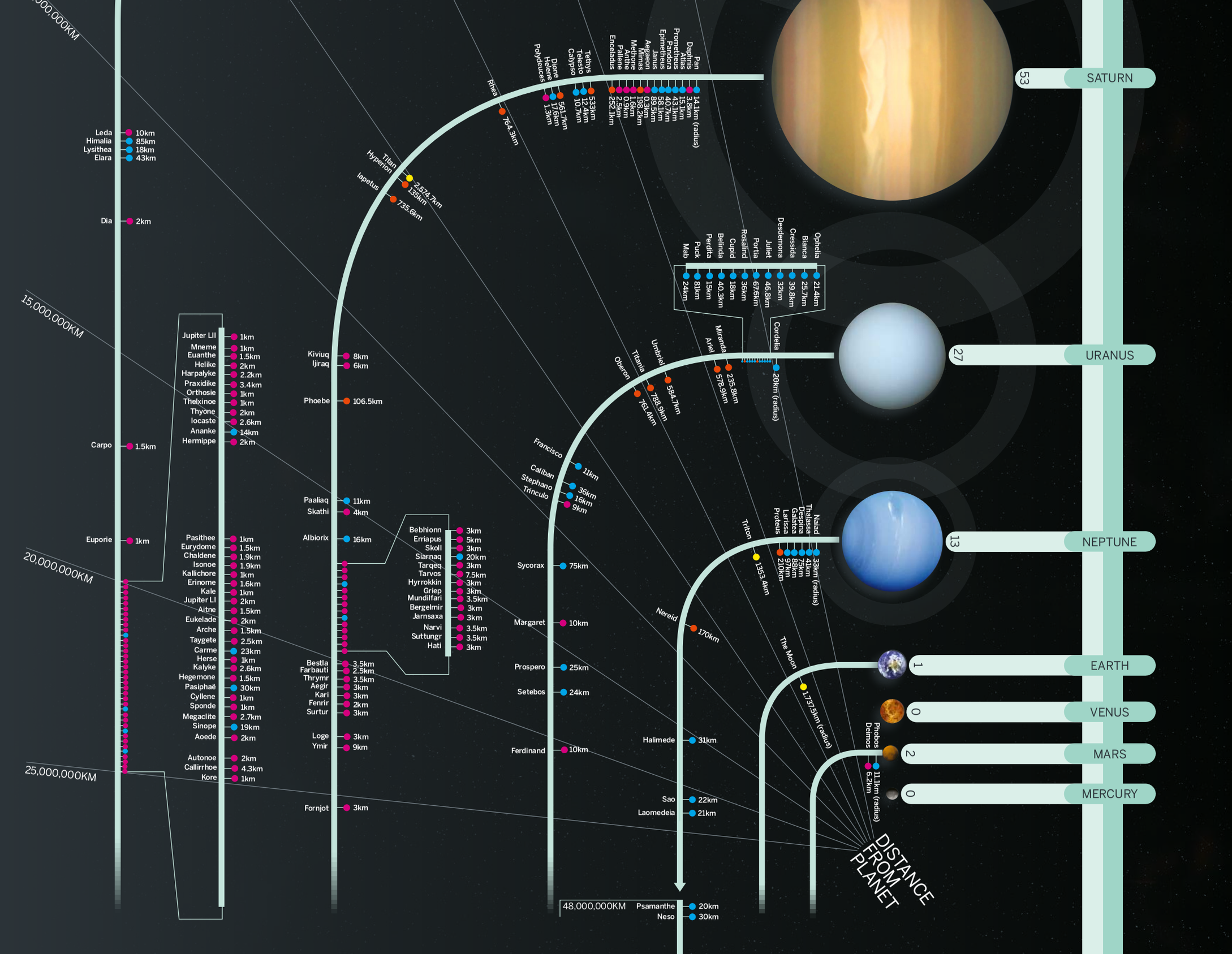
PLANETS (IN SIZE ORDER)
NO. OF MOONS





Orbital periods

A year is defined as the time taken to orbit a host body, while a day is the time taken for the orbiting body to complete a rotation. Generally, the further a moon is from a planet the longer it will take to orbit it. However, it also depends on the mass of the planet. Here we compare the time taken for various moons to orbit their host planet and their distance from that planet. All times are given in Earth time scales.


15,000,000KM
20,000,000KM
25,000,000KM
48,000,000KM
Leda 10km
Himalia 85km
Lysithea 18km
Elara 43km
Dia 2km
Carpo 1.5km
Euporie 1km
Jupiter LII 1km
Mneme 1km
Euanthe 1.5km
Helike 2km
Harpalyke 2.2km
Praxidike 3.4km
Orthosie 1km
Thelxinoe 1km
Thyone 2km
Iocaste 2.6km
Ananke 14km
Hermippe 2km
Pasithee 1km
Eurydome 1.5km
Chaldene 1.9km
Isonoe 1.9km
Kallichore 1km
Erinome 1.6km
Kale 1km
Jupiter LI 2km
Aitne 1.5km
Eukelade 2km
Arche 1.5km
Taygete 2.5km
Carme 23km
Herse 1km
Kalyke 2.6km
Hegemone 1.5km
Pasiphaë 30km
Cyllene 1km
Sponde 1km
Megaclite 2.7km
Sinope 19km
Aoede 2km
Autonoe 2km
Callirrhoe 4.3km
Kore 1km
Kiviuq 8km
Ijiraq 6km
Phoebe 106.5km
Paaliaq 11km
Skathi 4km
Albiorix 16km
Bebhionn 3km
Erriapus 5km
Skoll 3km
Siarnaq 20km
Tarqeq 3km
Tarvos 7.5km
Hyrrokkin 3km
Griep 3km
Mundilfari 3.5km
Bergelmir 3km
Jarnsaxa 3km
Narvi 3.5km
Suttungr 3.5km
Hati 3km
Bestla 3.5km
Farbauti 2.5km
Thrymr 3.5km
Aegir 3km
Kari 3km
Fenrir 2km
Surtur 3km
Loge 3km
Ymir 9km
Fornjot 3km
Rhea 764.3km
Titan 2,574.7km
Hyperion 135km
Iapetus 735.6km
Pan 14.1km (radius)
Daphnis 3.8km
Atlas 15.1km
Prometheus 43.1km
Pandora 40.7km
Epimetheus 58.1km
Janus 89.5km
Aegaeon 0.3km
Mimas 198.2km
Methone 1.6km
Anthe 1.8km
Pallene 2.5km
Enceladus 252.1km
Tethys 533km
Telesto 12.4km
Calypso 10.7km
Dione 561.7km
Helene 17.6km
Polydeuces 1.3km
Ophelia 21.4km
Bianca 25.7km
Cressida 39.8km
Desdemona 32km
Juliet 46.8km
Portia 67.6km
Rosalind 36km
Cupid 18km
Belinda 40.3km
Perdita 15km
Puck 81km
Mab 24km
Cordelia 20km (radius)
Ariel 578.9km
Miranda 235.8km
Umbriel 584.7km
Titania 788.9km
Oberon 761.4km
Francisco 11km
Caliban 36km
Stephano 16km
Trinculo 9km
Sycorax 75km
Margaret 10km
Prospero 25km
Setebos 24km
Ferdinand 10km
Psamanthe 20km
Neso 30km
Naiad 33km (radius)
Thalassa 41km
Despina 75km
Galatea 88km
Larissa 97km
Proteus 210km
Triton 1353.4km
Nereid 170km
Halimede 31km
Sao 22km
Laomedeia 21km
The Moon 1,737.5km (radius)
Phobos 11.1km (radius)
Deimos 6.2km
53 SATURN
27 URANUS
13 NEPTUNE
1 EARTH
0 VENUS
2 MARS
0 MERCURY
DISTANCE FROM PLANET

EXTREME SPORTS

BRAVE ATHLETES PUSH THE LIMITS OF PHYSICS, CHEMISTRY AND BIOLOGY TO PERFORM INCREDIBLE FEATS

Words by **Laura Mears**

BASE jumping

Dicing with physics to conquer death-defying drops

Extreme sports pit humanity against science to find out just how far we can go. We've learnt to defy physics, harness chemistry and push the biology of the human body to its limits.

Vittorio Innocente combined physics, engineering and biology to ride a bicycle 66.5 metres under the sea. Ivan Trifonov flew a hot air balloon in a cave 206 metres under the ground. We also have Donald Cripps, who in 2013 aged 84 years 37 days, parachuted off America's New River Gorge Bridge, playing with gravity and air resistance to land a perilous BASE jump.

Skateboarders harness pendulum physics to swing up and down a halfpipe. Snowboarders ride on water chemistry. Marathon runners toy with the limits of their own physiology. Rock climbers tame unconquerable peaks with friction. All are adrenaline junkies who push their bodies to the edge to chase that extreme-sports high. When we conquer our limitations and challenge the physics of our environment we can achieve some amazing things.

"BASE jumpers have seconds to open their parachutes, and every movement counts"

BASE jumping is so dangerous that it's banned in many countries

Skydivers open their ram-air parachutes at around 600 metres. These rectangular sheets of fabric have two layers divided into cells that fill with air. When fully deployed, they make an aerofoil shape that works like a wing. The air resistance opposes the force of gravity, reducing the terminal velocity of the jumper by over 90 per cent. Instead of hitting the floor at around 55 metres per second they slow down to around five. BASE jumpers take parachuting to the next level by leaping much closer to the ground.

The 'BASE' in BASE jumping stands for 'building, antenna, span and Earth'. BASE jumpers launch off from one of these objects (a span is a bridge), starting their descent at below 610 metres, sometimes as low as 91 metres. The thrill is in the timing. They have seconds to open their parachutes, and every movement counts.

A wingsuit turns their arms into gliders, and they often hold their parachutes so that they can deploy them manually. Some even use a static line connected to the object they've just jumped from to automatically pull the parachute open as they fall.

Terminal velocity

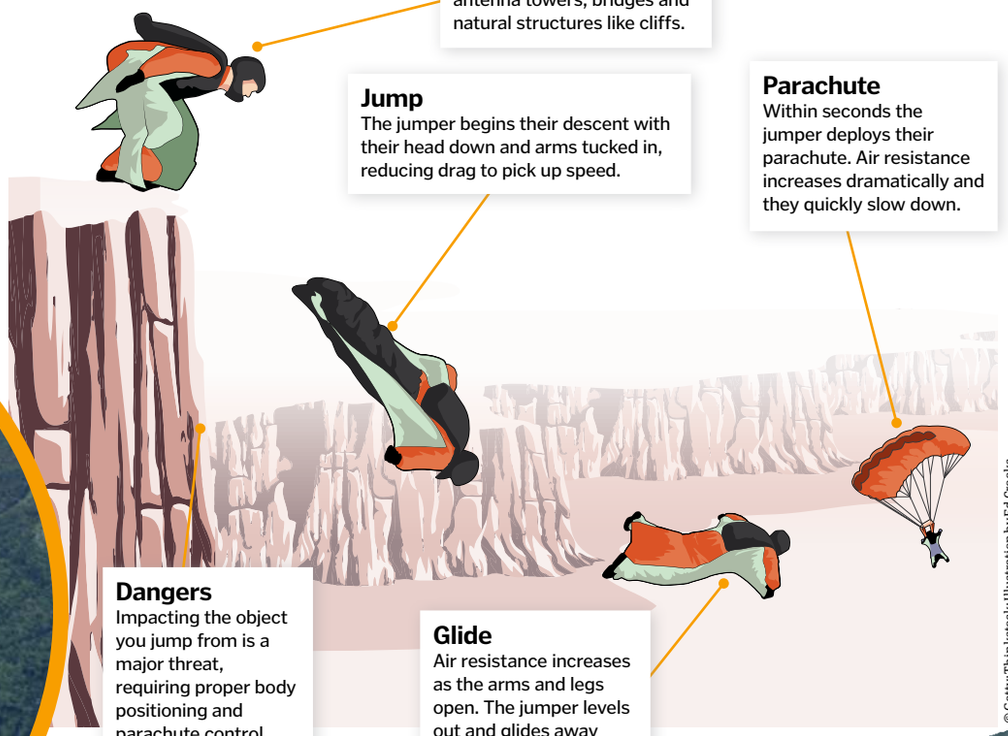
Terminal velocity is the maximum speed an object can reach when falling. It depends on two things: the object's weight and the resistance working in the opposite direction.

A BASE jumper accelerates towards the ground when they jump, dragged down by gravity. As they do this they bump into particles of air, which exert an upward force on their body. The faster they go, the harder they hit the air particles and the more resistance they meet. Eventually, the upward force of the air resistance equals the downward force of gravity and they can't go any faster. Wingsuits and parachutes increase the surface area, hitting more air particles and reducing the terminal velocity.

Free-falling skydivers experience more air resistance as they get faster

Anatomy of a BASE jump

Jumpers have just a few seconds to time the perfect fall



Rock climbing

Friction keeps climbers from plummeting to the ground

Climbers battle gravity to ascend cliff faces. Friction is a fundamental part of their sport, and it works because the rock and the climber's hands and feet aren't smooth. The surfaces might look slippery, but microscopic lumps and bumps lock together as the climber grips on. To climb effectively they need to maximise the contact between their hands and the rocks, boosting the friction.

If the rock face is too jagged, the contact area drops, but climbers can boost their grip by changing their kit. Rubber (on climbing shoes or gloves) deforms as it comes into contact with rock, wrapping around the surface and increasing the contact area. This allows more of the microscopic lumps to cling together. Even so, climbers must pay attention to the temperature. If it's too hot, rubber softens and becomes slippery. However, if it's too cold it becomes too hard to wrap around the rock face. Either situation can spell serious trouble.

Chalk improves grip by absorbing sweat, stopping bare hands from slipping

The harder a climber pushes in to the rock, the more friction there is

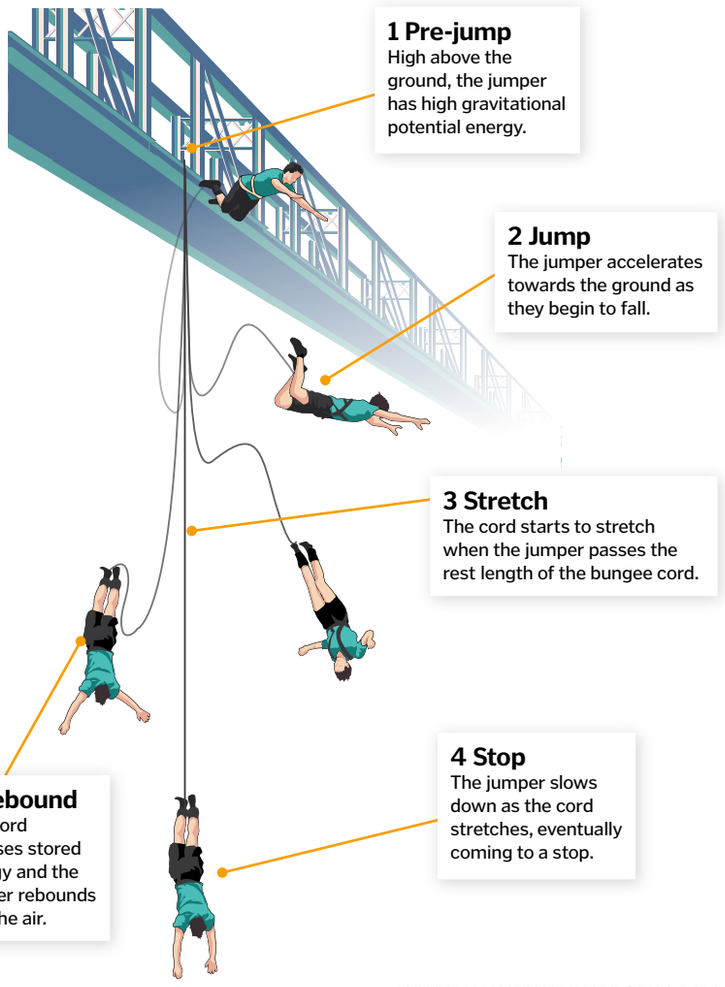
"Climbers can boost their grip by changing their kit"

Bungee jumping

This thrill-seeking activity uses elasticity to store and release the energy of a fall

Bungee jumping is a classic extreme sport because it plays with the laws of physics. The jumper drops through the air without a parachute. With the added mass of the slack bungee cord beneath them, they pick up speed faster than a skydiver. The bungee cord is slack at first, but when they reach the end it starts to pull. As it stretches it stores elastic potential energy like a spring. This slows the bungee jumper until the upward pull of the cord matches the downward pull of gravity and they come to a momentary stop. At the bottom of the jump, the cord releases its energy, propelling the jumper back up.

The weight of the bungee cord makes the jumper fall faster



1 Pre-jump
High above the ground, the jumper has high gravitational potential energy.

2 Jump
The jumper accelerates towards the ground as they begin to fall.

3 Stretch
The cord starts to stretch when the jumper passes the rest length of the bungee cord.

4 Stop
The jumper slows down as the cord stretches, eventually coming to a stop.

5 Rebound
The cord releases stored energy and the jumper rebounds into the air.

Marathon

This 26.2-mile race pushes the body to its limits

Marathon runners cover between 30,000 and 50,000 steps in a single race. As the numbers rack up the body takes a beating. The heart and lungs work overtime to supply the muscles. The body mobilises energy stored in the liver and fat. The skin and digestive system switch to low-power mode. Maintaining a steady state under such extreme exertion is a serious challenge.

The body has two main energy stores. Glycogen is an instant-access carbohydrate stored in the liver and muscles. It can be easily burnt for fuel, but the body can only store enough for two hours or so. When it runs out runners hit 'the wall'. Fat is harder to burn, but packs more calories per gram than carbs and there's more of it. Endurance training helps marathon runners train their muscles to use fats first, and to delay the wall they can 'carb load', filling their instant stores to the brim.

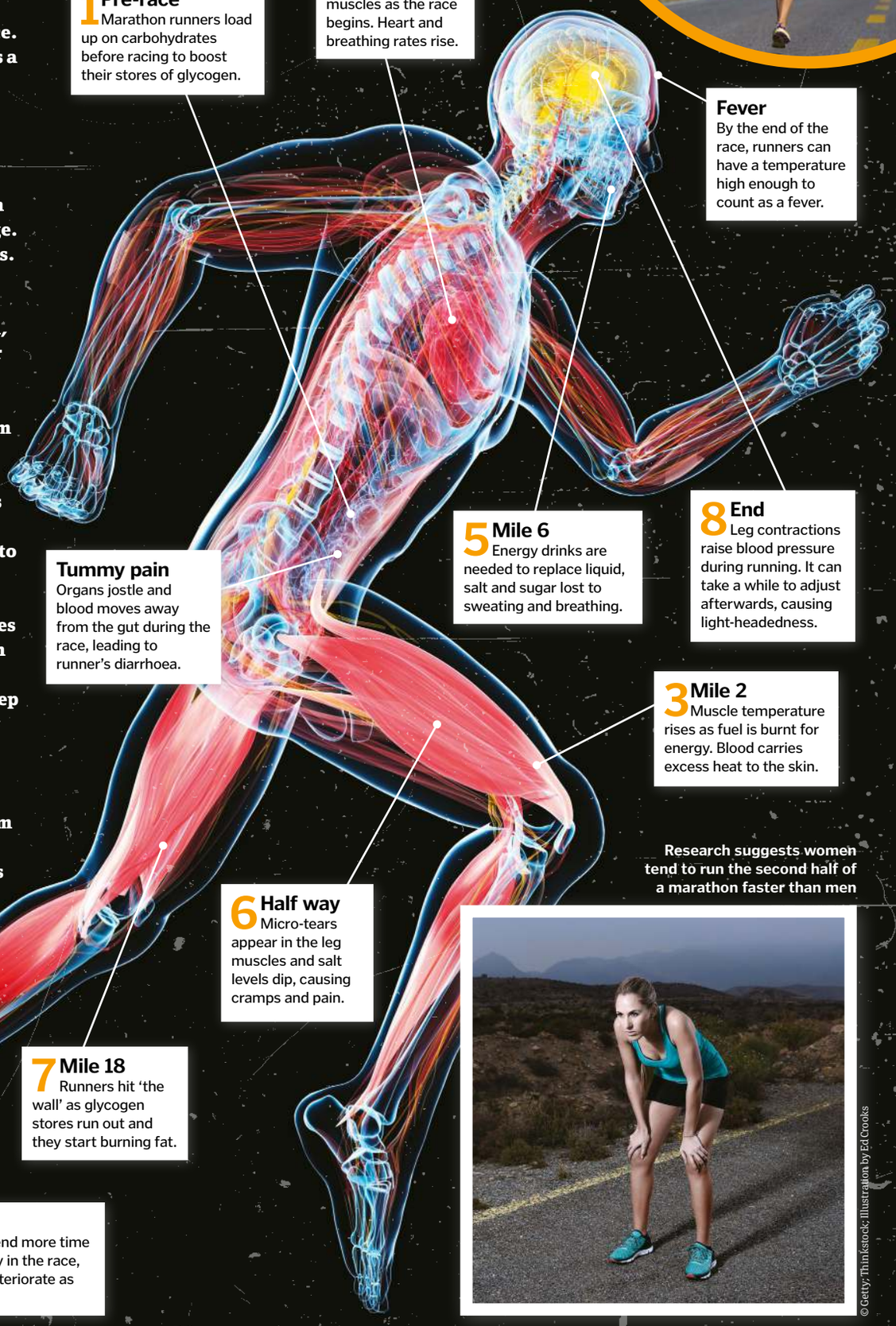
With energy sorted, the next challenge is temperature. Busy muscles get hot fast. Runners can lose up to ten per cent of their body weight during a race just by sweating. This helps to keep temperatures down but triggers a new problem – managing salt and water.

Sodium is critical for muscle contraction, powering not only our arms and legs but heart and diaphragm too. If levels drop too low tissues can swell. To survive a marathon, runners have to fuel up on sports drinks to restore vital liquid, electrolytes and sugars.

The marathon body

Extreme exercise pushes the body to its limits every hour of the race

Runners hit 'the wall' when their stores of glycogen begin to run out



1 Pre-race
Marathon runners load up on carbohydrates before racing to boost their stores of glycogen.

2 Start line
Blood floods the muscles as the race begins. Heart and breathing rates rise.

Fever
By the end of the race, runners can have a temperature high enough to count as a fever.

Tummy pain
Organs jostle and blood moves away from the gut during the race, leading to runner's diarrhoea.

5 Mile 6
Energy drinks are needed to replace liquid, salt and sugar lost to sweating and breathing.

8 End
Leg contractions raise blood pressure during running. It can take a while to adjust afterwards, causing light-headedness.

3 Mile 2
Muscle temperature rises as fuel is burnt for energy. Blood carries excess heat to the skin.

6 Half way
Micro-tears appear in the leg muscles and salt levels dip, causing cramps and pain.

7 Mile 18
Runners hit 'the wall' as glycogen stores run out and they start burning fat.

4 Mile 4
The feet spend more time off the floor early in the race, but stride will deteriorate as the miles pile up.

Research suggests women tend to run the second half of a marathon faster than men

Snowboarding

How does water chemistry affect snowboard speed?

Snowboarders harness gravity to pick up speed on halfpipe slopes. To maximise air time they 'pump' with their legs. At the bottom of the pipe they bend their knees, coiling up like a spring to store extra energy. On the way up they release, pumping the stored energy into the kinetic energy of the jump. The effect is like swinging on a swing, but there's more than just physics at work. To get the speed they need to perform aerial tricks, snowboarders rely on chemistry too.

As the board passes over the halfpipe some of the kinetic energy converts into heat, melting a layer of snow. This forms a film of water that acts as lubricant. The board no longer comes into contact with the snow and it hydroplanes, massively reducing friction. This is perfect for a speedy launch, but the effect doesn't last all day.

As the Sun beats down, or as more and more competitors ride the halfpipe, the amount of melted water starts to rise. Then cohesion kicks in. Sticky snow clings to the board, slowing everything down. As the surface refreezes at night, it becomes icy and hard. This makes things slippery, but turning becomes more difficult because the board can't dig into the snow. Competitors have to change their equipment and tactics depending on the science beneath their feet.

The science of stunts

Snowboarders play with physics to pick up speed for halfpipe tricks

The curved shape of a snowboard helps it to carve through the snow on turns

Flips
Arm and leg movements power tricks as the snowboarder spins.

Rotations
The laws of conservation of momentum prevent the snowboarder changing their overall direction in the air, even when they flip and spin.

Acceleration
Gravitational potential energy becomes kinetic energy as the snowboarder travels down the slope.

Coil
The snowboarder coils up as they approach the jump.

"Adrenaline junkies just keep going back to get that hormone rush"

Adrenaline junkies

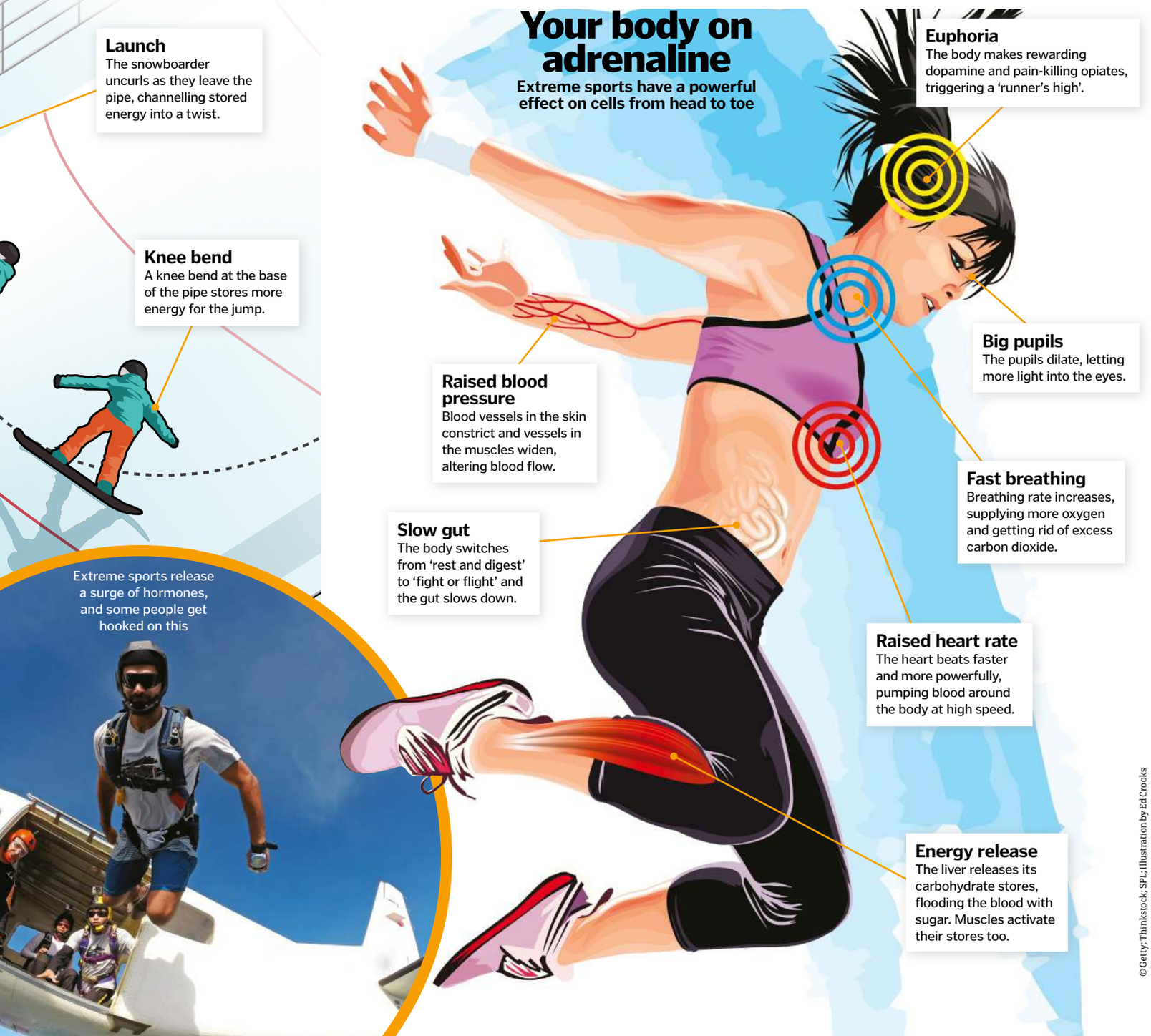
Why do some people get hooked on extreme sports?

When the body activates its fight or flight system, within two to three minutes hormones flood into the bloodstream. The adrenal glands, which sit on top of the kidneys, produce adrenaline in response to signals from the brain. Also known as epinephrine, its job is to prepare the body for action.

Adrenaline raises the heart rate, increases breathing and triggers energy release. It diverts resources away from the skin and gut and towards the muscles, and it makes us more alert and more responsive, so much so that some people can get hooked on the feeling.

There are three parts to addiction, and their intensity differs from person to person. The first is 'sensation-seeking' – trying new experiences and feeling new things. The next is 'impulsivity' – how much self-control we have. The last is 'compulsivity' – the tendency to repeat actions again and again.

Our brains reinforce positive behaviours by releasing pleasurable chemicals like dopamine and opiates. Exercise can trigger dopamine release, feeding the brain's reward pathway. It also kick-starts morphine production. This natural painkiller can cause euphoria, or a 'runner's high'. Though there's no medical addiction to adrenaline, we are hard-wired to seek these rewards. Adrenaline junkies just keep going back to get that hormone rush.



Have you read this before?

Discover the science of déjà vu and the technique used to trigger it

Déjà vu is more common in younger people, becoming less common as we age

Around 70 per cent of us experience it, in particular those of us aged 15–25, and it can be one of the most jarring feelings: déjà vu. French for 'already seen', it has previously been linked to the theory of false memories; the idea that we can view something once and when exposed to a scene or situation that is similar our brain will respond by creating a memory that didn't really happen. However, an experiment led by psychology researcher Akira O'Connor in 2016 revealed that this might not be the case. Rather than false memory, the brain is memory checking and sending an error message, signalling what we have actually experienced versus what we think we have experienced. Around 70 per cent of us experience...wait a minute...

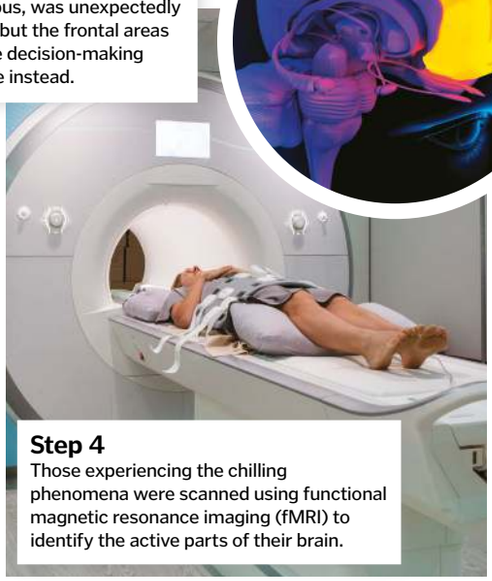
O'Connor's experiment

How did scientists artificially trigger déjà vu in the study's volunteers?

Step 1
Participants were given a list of words to remember including bed, pillow, dream and doze; all words that are connected, in this case, to the word 'sleep'.

Step 2
They were then asked if any of the words began with the letter 'S'. Of course, each person said no.

Step 3
Later on, the volunteers were asked if the word 'sleep' was included in the previous list of words. This prompted a feeling of déjà vu.



Step 4
Those experiencing the chilling phenomena were scanned using functional magnetic resonance imaging (fMRI) to identify the active parts of their brain.

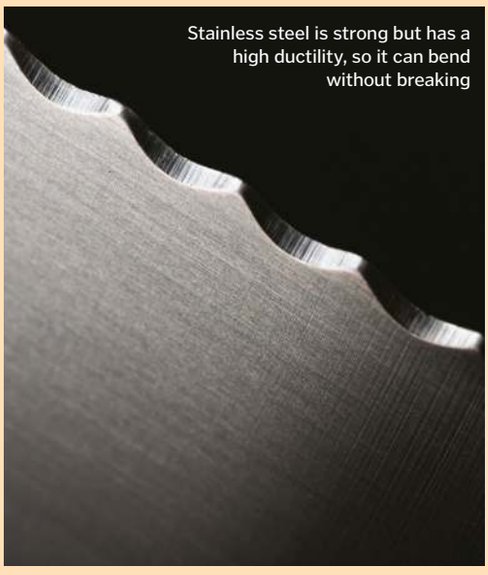
Step 5
Scans revealed that the memory centre of the brain, the hippocampus, was unexpectedly not active, but the frontal areas that handle decision-making were active instead.

Stainless steel

How does this everyday super-material fight the persistent forces of corrosion?

Stainless steel is an iron alloy with a minimum of 10.5 per cent chromium. Since its discovery in 1913 by metallurgist Harry Brearley, stainless steel has played an essential role across multiple industries. From medical instruments to street furniture, pots and pans and even chemical tankers, stainless steel is an incredibly useful material, saving structures from rust or corrosion. But since it is comprised mainly of iron, why doesn't this metallic marvel rust?

Rust is the result of iron oxidation, either from the air or from oxygen in water. The added element of chromium reacts with invading oxygen, acting as what is known as a passive layer, protecting the alloy's surface. This protection is further supported by the inclusion of other elemental sidekicks in the iron alloy, such as nickel, nitrogen, molybdenum, manganese and silicon. Even so, stainless steel does have a weakness; it is susceptible to chlorides found in salt water, which can break through the protective layer.



Stainless steel is strong but has a high ductility, so it can bend without breaking

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Clinical trials

New medicines must pass three rigorous stages of testing before they're ready for patients

KEY

- Positive outcome
- Neutral or negative outcome – trial ends
- Review by independent panel of experts
- Protocol development, data analysis and publication

Scientists learn more about human health and disease every day, but discoveries made in the lab can't go straight into hospitals. Drugs that work well on cells in test tubes or on lab mice might not behave the same way in people. We need to test them on humans to find out whether they are safe, effective and better than what's currently available, but this can be dangerous. Clinical trials are carefully controlled experiments designed to take new medicines into hospitals for the first time.

IN THE LAB

Discovery scientists work to understand the molecular biology of disease. Using this knowledge, translational biologists and pharmacologists can then design potential treatments. These are first tested on cells in test tubes and then in animals, most often mice and rats.

~4.5 years

1. Develop the concept
2. Acquire funding
3. Test in the laboratory

PLANNING THE TRIAL

Testing new drugs in people for the first time can be dangerous. Scientists work together with doctors, nurses and trial specialists to ensure that trials are as safe as possible. They identify potential risks and design tests to monitor the treatment and its effects on the trial participants.

~6 months

When

Each clinical trial needs careful planning. The team decide how many people to recruit, how to test the treatment, what to track and what outcomes to look for.

PHASE 0

Before new treatments enter the first phase of clinical trials, there may be a pilot study to find out how the molecule behaves in the body. The aim is to watch where the treatment goes and what the body does to it. Phase 0 trials use very small doses and are tested on a very small number of people.

~1 year

Why

Molecules often act differently in the body compared to the lab. Phase 0 trials help to speed up development by finding out how brand new molecules behave in people.

PHASE I

When new drugs are first used doctors don't know what dose to give. The first stage of clinical trials uses a technique called 'dose escalation' to find out how much is safe. Healthy volunteers are given the drug, starting at very low amounts. The dose is slowly increased until side-effects start to emerge.

~6 months

Who

Phase I clinical trials recruit between 20–100 people. They are usually healthy volunteers, but for some types of drugs (like cancer treatments) they are patients.

"Clinical trials test whether new treatments are safe and effective"

PHASE II

Once the team have worked out the safe dose, it's time to test the treatment in sick people to see if it works. Phase II trials recruit patient volunteers. The team monitor them throughout for any improvement in their condition and for side-effects. Only around one-third of drugs will move onto the next phase.

PHASE III

The final phase of testing before medicines can be widely used is a phase III trial. These pit promising new drugs against the current gold standard treatment to see if they work better. Half of the patients get the new treatment and the other half – the 'control' group – receive the current treatment.

NUMBER CRUNCHING

Statisticians and clinical trial specialists analyse trial data at every stage. Trial staff monitor participants closely to work out whether the medicine is behaving as it should. They compare data gathered from people receiving the treatment to people receiving the control, or placebo.

PHASE IV

Phase III trials test new treatments on thousands of people, but some effects don't become clear until later. Follow-up studies monitor people taking the new treatment after it is licensed. These look at how treatments affect people over the long term and how they interact with other medicines or illnesses.

~3 years

~2–4 years

~6 months

~1.5 years

Who

Hundreds of people join phase II clinical trials. They are patients with the disease that the new drug aims to treat. They are only offered a place if they meet certain criteria.

Where

Phase I clinical trials happen in one place. Phase II and III trials happen across many hospitals at the same time. Sometimes trials run internationally.

How

Trial participants join the test or control group at random. Often, neither they nor the doctors know which group they are in until the trial ends. This helps to reduce bias.

DRUG OR TREATMENT APPROVED

Is it safe and effective?

Does it have appropriate labelling quality control?

What is a hernia?

Weakened muscles can lead to some serious side effects

Usually, your muscles are strong enough to hold your organs, but when they are weak it is possible that part of an organ can be pushed out through the wall of the cavity containing it, resulting in a hernia.

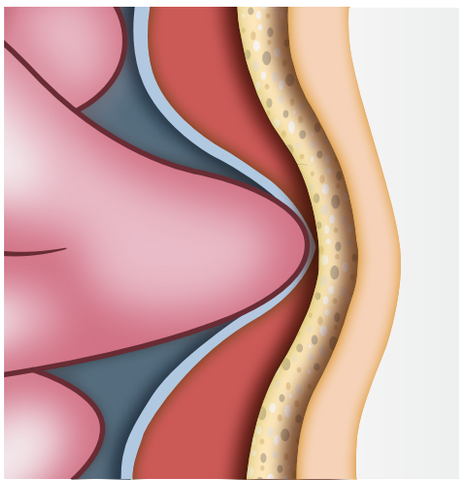
The most common type of hernia occurs when the intestines protrude through the abdominal muscle, leaving an unpleasant and often uncomfortable bump under the surface of the skin. Hernias can be caused when lifting heavy objects or by persistent coughing, and they are more common in older people.

Surgery can repair such injuries, pushing the bulge back into its correct place and strengthening the weakness in the muscle. However, complications can sometimes occur. Hernias around the intestines can obstruct the flow of the digestive tract, causing nausea and vomiting, or strangulation – a medical emergency that requires immediate attention if permanent damage is to be prevented.

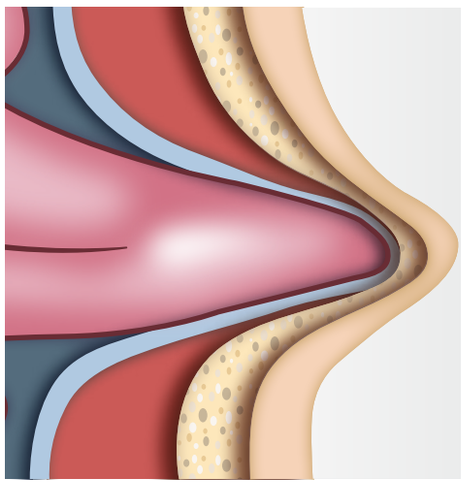
"Hernias can be caused when lifting heavy objects or by persistent coughing"

Strangulated hernia

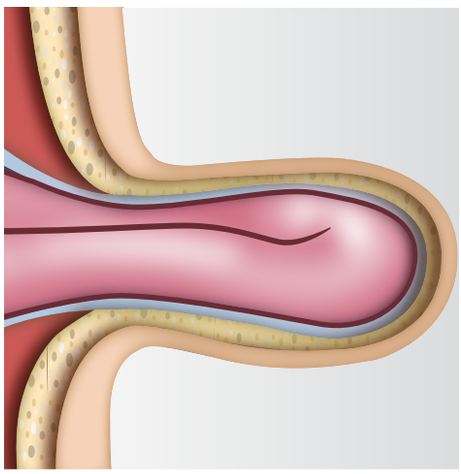
A strangulated hernia is a medical emergency – immediate attention is needed to reduce the risk of permanent damage to the intestinal tract



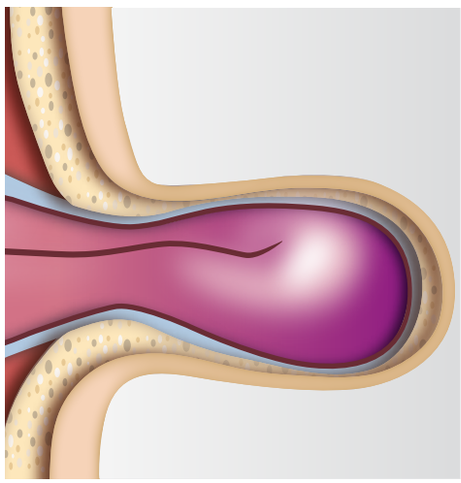
Weakened muscle
The abdominal wall weakens and becomes unable to hold the intestines in place effectively.



Protrusion of intestine
The intestines push outwards at a particularly weak point, often as a result of over-exertion of the muscle.



Intestines become trapped
A section of the intestines can become trapped by the surrounding tissue and unable to be pushed back inside.



Restricted blood flow
The trapped section can become 'strangled' as its blood supply is cut off. This causes the trapped tissue to die, causing severe pain and requires urgent surgery.

Atomic energy levels

How atoms absorb or release energy depending on their electron arrangement

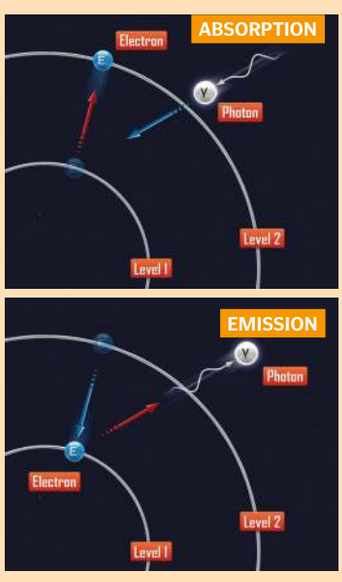
An atom's electrons orbit the nucleus at specific energy levels. The easiest way to imagine this concept is with a simplified atomic model, in which electrons orbit the nucleus like planets orbit a star.

Each defined orbit is known as an energy level. Electrons must have a certain amount of energy to orbit within each level, and this amount increases the further away an energy level is from the nucleus.

Electrons can gain or lose energy. If an electron absorbs enough energy to move up to the next energy level it is said to be in an excited state. The electrons in a substance can become excited if the matter is heated or if it absorbs pulses of electromagnetic radiation, such as light photons.

Being excited is an unstable state, so the electron eventually returns to its original, lower-energy level. This transition leads to the emission of a photon with the same amount of energy as the difference between the two energy levels it moves between.

The atoms of different elements have specific energy levels, so they will absorb and emit photons of different energies. Measuring the properties of photons absorbed or emitted by a substance can be used to identify what elements it contains.



Absorbing a photon of a specific energy allows an electron to move to a higher energy level (top). When it eventually moves back to its original energy level, a photon is emitted (bottom).

How do we sense time?

The science behind why time flies when we're having fun

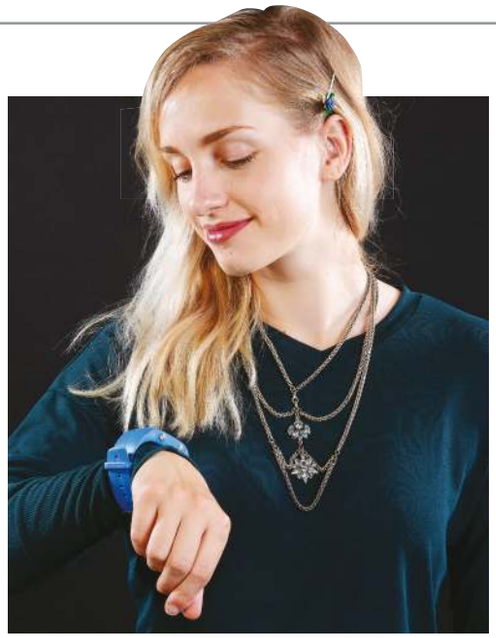
When you are waiting for a bus you can usually estimate how long you've been standing there. Our ability to keep track of time is important in almost every aspect of day-to-day life, from playing a musical instrument to holding a conversation.

That little internal alarm that says you've been standing in the shower for too long comes from a type of temporal processing supported by two neural clocks. Researchers previously thought that our intuitive timekeeping ability came from a part of the brain called the striatum. Studies have shown that this region is activated when people pay attention to time, and patients with Parkinson's disease – which disrupts the striatum – can have difficulty telling the time.

Scientists predict that the striatum consistently pulses with activity, a little bit like the ticking of a clock. However, recent studies suggest that in order to be conscious of the passage of time your brain also relies on the hippocampus to remember how many pulses from the striatum have occurred. This concept is known as the interval timer theory, and it explains how we unconsciously judge time spans on the scale of seconds to hours.

You will notice that time spent with your friends seems to pass much faster than when you're writing an assignment. Neuroscientists have found that this is because your brain stops recording these pulses of activity when you stop paying attention to time, such as when you're engrossed in an activity. When this happens, the brain puts fewer 'ticks' of its internal clock in storage, making it feel like less time has passed.

On the other hand, in situations where you are more actively aware of the time – like when you're waiting for a delayed appointment – your mind will be counting every tick because you have little else to distract yourself with, making the passage of time feel much slower. So the next time you find that the day is dragging on, try to take your mind off the time to distract your internal clock.



If you want time to feel like it's flowing faster stop watching the clock!

Studies have found that the accuracy of our interval timers ranges from five to 60 per cent

Your brain's internal clock

The interval timer theory explains how your brain keeps time like a neurological metronome

1 Start the clock

A 'start' signal is activated by the onset of an event that lasts a familiar amount of time, such as the three minutes it takes to boil some water in a kettle.

2 Synchronisation

This triggers specific cortical nerve cells (which usually fire at different speeds, shown in A) to briefly fire together at the same time (B). They then return to their original firing rates, but because they all started simultaneously their activity follows a particular pattern.

3 Dopamine

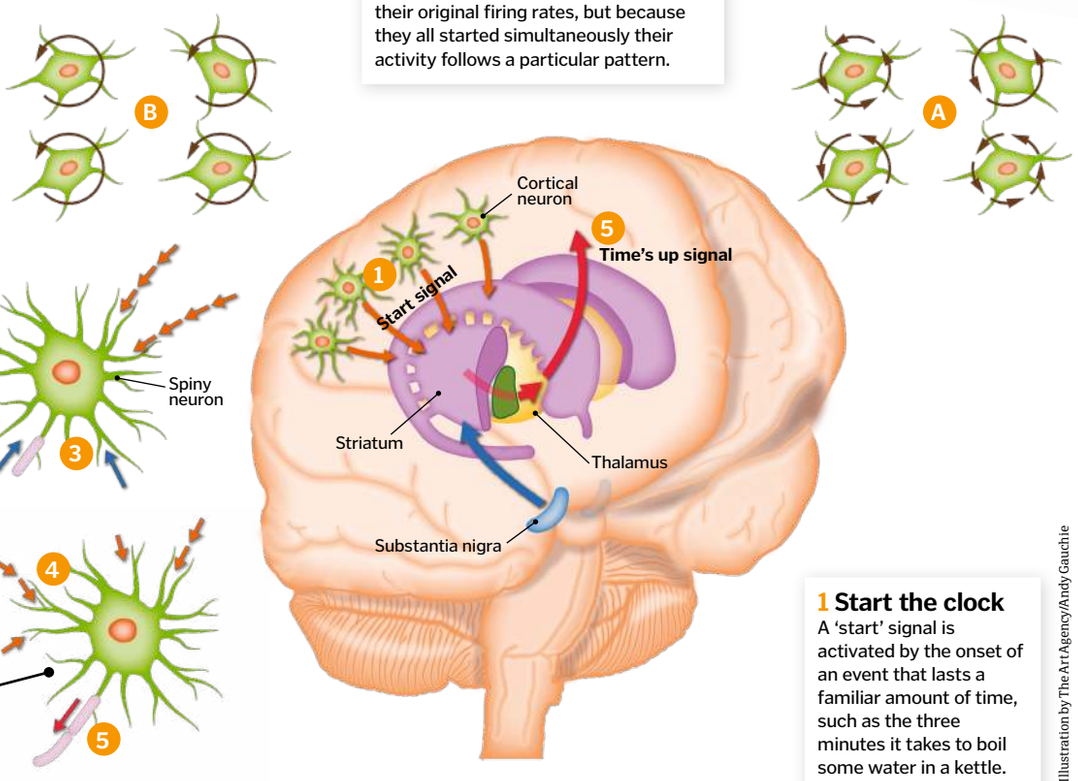
A subtype of brain cells called spiny neurons monitor the cortical neurons' activity, keeping track of how many times their firing patterns repeat. When the event finishes – in this case, once the kettle has boiled – bursts of dopamine are sent towards the striatum.

4 Memory

The release of dopamine causes the spiny neurons to commit the firing pattern of the cortical neurons at that particular instant to memory. This creates a kind of 'time stamp' for the given event. Research suggests that there are unique memories for a whole range of different intervals.

5 Time's up

Now the spiny neurons have 'learned' these intervals they will monitor cortical firing rates until they match the memory for the time stamp that signals that particular event is over. Once this occurs the striatum sends signals to other areas of the brain involved in memory and decision making, giving you an internal 'time's up!' alert.



IT'S MORPHING TIME

Discover the transformative power of metamorphosis and the range of species that undergo it

Words by **Scott Dutfield**

As children we are taught the simple transformations of some species; the iconic blossoming of a butterfly and the tail-shedding cycle of tadpoles, for example. Known as metamorphosis, this process completely changes an animal's anatomy. However, this transformation is far from simple and spreads across a wide range of species.

At first glance, it's easy to come to the conclusion that a caterpillar and butterfly could be identified as two completely different species. English physician William Harvey did just that in 1651, describing metamorphosis as a process whereby free-living embryos had escaped eggs, which provided little nutritional value. He also suggested that what we now know is the pupa stage was in fact a second egg from which a new species was reborn. Dutch biologist Jan Swammerdam later discredited Harvey's theory in 1669 when he realised that the larva, pupa and adult stages all belonged to a single species.

> *"Metamorphosis is far from simple and spreads across a wide range of species"*

There are two different types of metamorphosis: complete and incomplete. The differences between the two isn't whether or not a tadpole becomes a complete frog versus one that still has its tail; it relates to the species' level of anatomical change.

Complete metamorphosis occurs in those that completely change their physical characteristics, for example, a caterpillar changing into butterfly. On the other hand, incomplete metamorphosis results in only some changes, such as those seen in crickets, where the larval stage doesn't involve the development of wings but otherwise does look similar to its adult counterpart.

SHEDDING SKIN FOR WINGS

Insects are the most diverse class of animals on the planet, made even more diverse if you consider their change in forms, an occurrence that some undergo more than once in their lives. Some species start out in water as aquatic larvae, such as dragonflies, while others munch their way through vegetation on land. Many stay in their infant environment, but others decide to ditch walking or swimming and take to the skies. So how do insects shed their skin for wings?

Insect larvae carry a cellular bag of tricks within their bodies in order to carry out complete metamorphosis. Known as imaginal discs, these sac-like epithelial structures are

the driving force for insect transformation. Once a caterpillar or ladybird larva has finished a series of moulting (where it has shed its skin multiple times) it enters the pupa stage in a chrysalis. While snuggled up in its new home, digestive enzymes break down part the of larva's cellular structure with the exception of the imaginal discs. This creates a kind of chunky insect soup, with the imaginal discs playing the role of pieces of diced vegetables. During this process the discs begin to form the external structures of the soon-to-be butterfly. Working from the outside in, these structures will continue to form organs, wing veins and eyes.

Incomplete metamorphosis doesn't involve such an intense transformation. Crickets start out as nymphs rather than larvae, and instead of becoming a pupa they undergo several series of moulting, a process known as ecdysis. A nymph's exoskeleton will become too tight and, prompted by the juvenile hormone ecdysone, the nymph will form new skin and step out of the old one. The wings also develop at this stage, after which the nymph grows to its adult size.

TRADING TAILS FOR LEGS

The defining feature of amphibians is their ability to live both in water and on land, and much like insects, many amphibious species start out their lives in the water. However, unlike insects, when amphibians undergo the process of complete metamorphosis, there is a distinct lack of a chrysalis or cocoon to shelter a metamorphic soup.

In order to trade their tails for legs, most amphibians rely upon hormones to trigger the chain reaction of limb loss and limb growth while still swimming around. Thyroid hormones (TH) and prolactin hormones (PRL) are the predominant biological chemicals that control the process of metamorphosis. The two work together in a balancing act. TH is the agent of change and ultimately causes the gene expression that results in a frog's transformation, while PRL works as a blocker to TH. As a frog begins its life as a tadpole, the ratio of TH and PRL levels are low. As they move through the stages of metamorphosis, PRL levels will decrease as TH levels increase, allowing the frog's anatomy to change over time. This accumulation of chemicals results in amphibians making the necessary internal changes needed to survive for life on dry land.

Gills that formed in the larval/tadpole stages are now slowly absorbed and replaced with lungs. The intestinal structures in a larva are much longer than those of its future form; during metamorphosis this length is shortened. Larvae

Newt and salamander larvae present extending gills, which restrict and develop into lungs during metamorphosis

Dragonflies undergo incomplete metamorphosis; their marine-dwelling larvae have a similar anatomy as their adult forms

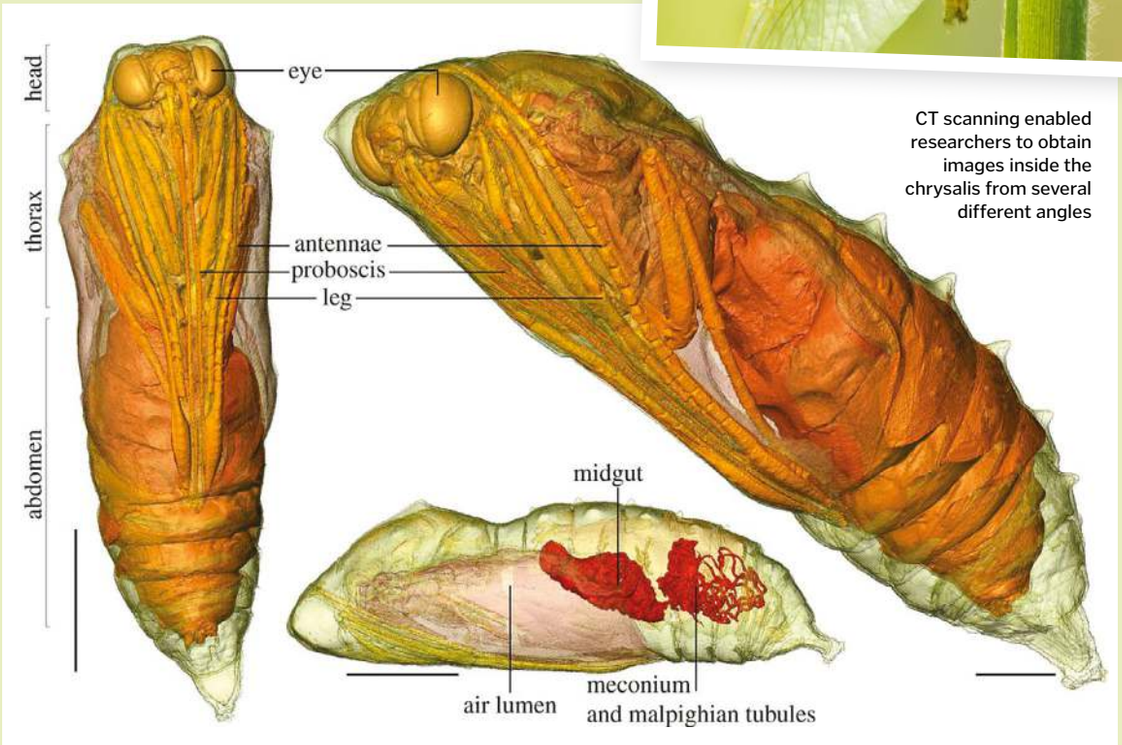
"The transformation process creates a kind of chunky insect soup"

Inside a chrysalis

A study in the Journal of the Royal Society Interface used X-ray computed tomography (CT scans) to create a 3D model of the stages of metamorphic development within a chrysalis. This technique is used in hospitals to scan human organs for damage.

Over 16 days, nine individual chrysalises were scanned at different stages of development. The scans revealed the visual internal growth of a butterfly's complex respiratory system, wing veins and creation of a waste system, known as Malpighian tubules. The gut of the larvae also becomes visibly shorter during the process of metamorphosis.

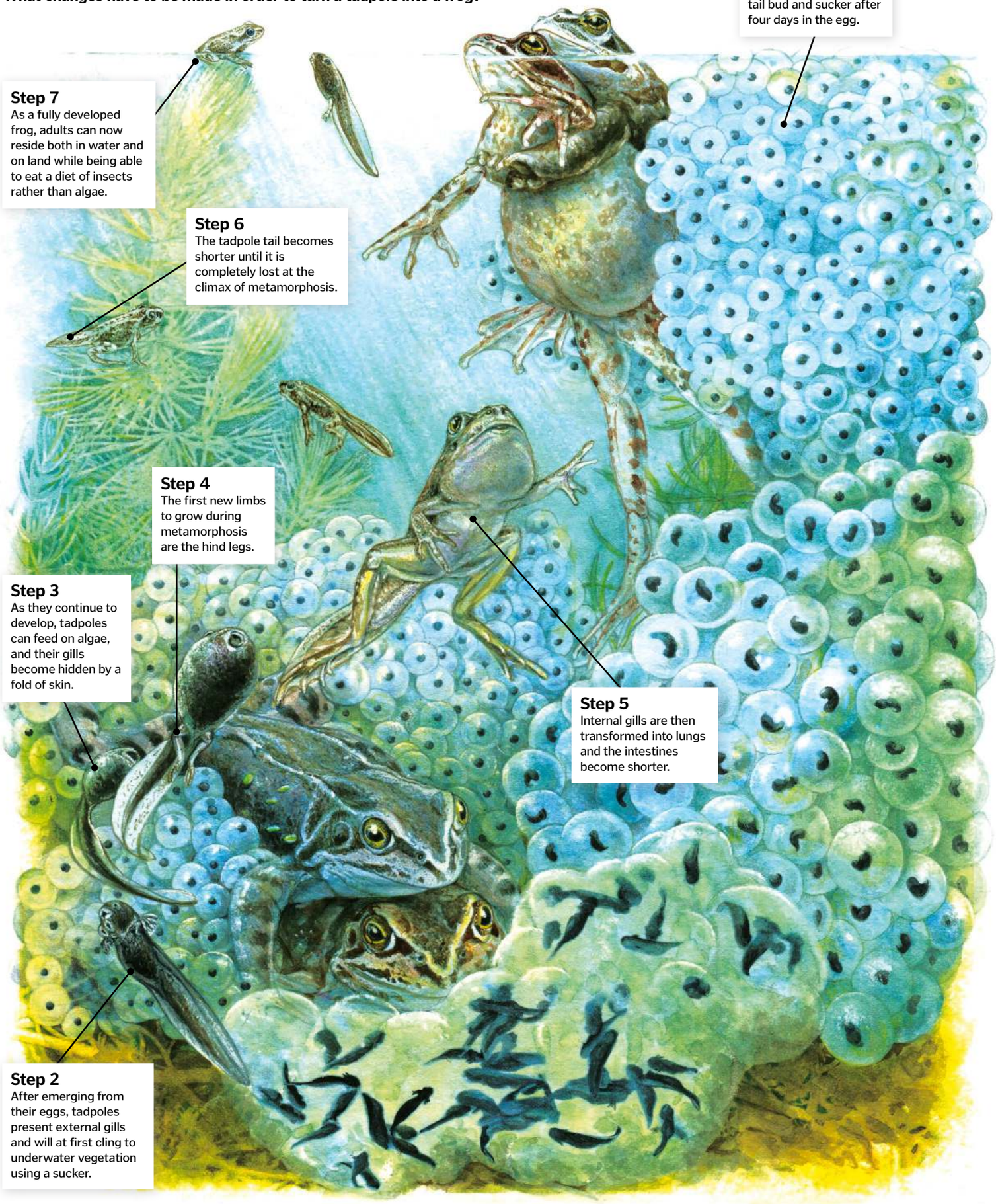
The study not only exposed the internal workings of insect transformations; the technique used will also enable us to study the effects of toxic chemicals on insect species and their development.



CT scanning enabled researchers to obtain images inside the chrysalis from several different angles

Frog metamorphosis

What changes have to be made in order to turn a tadpole into a frog?



Step 1
Frog embryos develop a tail bud and sucker after four days in the egg.

Step 2
After emerging from their eggs, tadpoles present external gills and will at first cling to underwater vegetation using a sucker.

Step 3
As they continue to develop, tadpoles can feed on algae, and their gills become hidden by a fold of skin.

Step 4
The first new limbs to grow during metamorphosis are the hind legs.

Step 5
Internal gills are then transformed into lungs and the intestines become shorter.

Step 6
The tadpole tail becomes shorter until it is completely lost at the climax of metamorphosis.

Step 7
As a fully developed frog, adults can now reside both in water and on land while being able to eat a diet of insects rather than algae.

feed on plant matter, which takes longer to digest than the insects that adults eat, therefore the intestines are longer in tadpoles than in adult frogs. The same is true in other amphibian species, such as newts and salamanders.

Studies have revealed that there are other forces that can trigger these biological transformations, in particular environmental ones. Ponds naturally dry up as the seasons change, and as this natural process begins it acts like an eviction notice for the salamander larvae, for example. In artificial recreations of these conditions, scientists found that as the oxygen and water levels of a dying pond decreased, larvae were prompted to hurry up and grow some legs and lungs, and sure enough they did.

TRANSFORMING BELOW THE TIDES

Metamorphosis isn't just seen in the bugs and frogs of the world but in many marine creatures too. Jellyfish undergo the process of biological transformation, similar to metamorphosis in insects. They begin their lives as a stalk-like polyp. Attached to the seafloor, over time the polyp will break down into segments and form tiny jellyfish in a process called strobilation. These baby jellyfish (ephyrae) will gradually grow into adults (medusa). In one particular species, known as the immortal jellyfish, this process can be reversed, allowing adults to revert back to their juvenile stage, essentially giving them ever-lasting life.

Another terrific marine transformer is the sea slug (nudibranch). Not only weird and wonderful in both their vibrant colour and odd physical forms, their microscopic transformations to become adults are also awe-inspiring.

Beginning life as tiny organisms called veligers, these mini sea slugs reside in their own microscopic shells, which they shed during metamorphosis and after eating a lot of plankton. In order for these sea slugs to develop into the oddities of the seafloor, their internal and external physicalities are both transformed.

CHANGING FOR SURVIVAL

It's clear that these animal transformers have a fascinating lifecycle, but why do they feel the need to change it all? Fossil records for insect metamorphosis date back 280–300 million years, and it's suggested that complete metamorphosis evolved from incomplete metamorphosis over time. The predominant theory as to why these transformations occurred in the first place was due to the need to reduce competition.

> "Creatures that could change form did so to ensure their survival"

It has been proposed that creatures that could change form did so to ensure their survival when competing for resources. A tadpole or dragonfly larva will take its food from the water, whereas their future selves get their food from above the surface. Having offspring that live in a different environment, or demand different resources, eliminates the competition between juveniles and adults, thus extending the chances of survival for both.

Nudibranches start life as microscopic-sized larvae that resemble a tiny sea snail before transforming into their adult forms

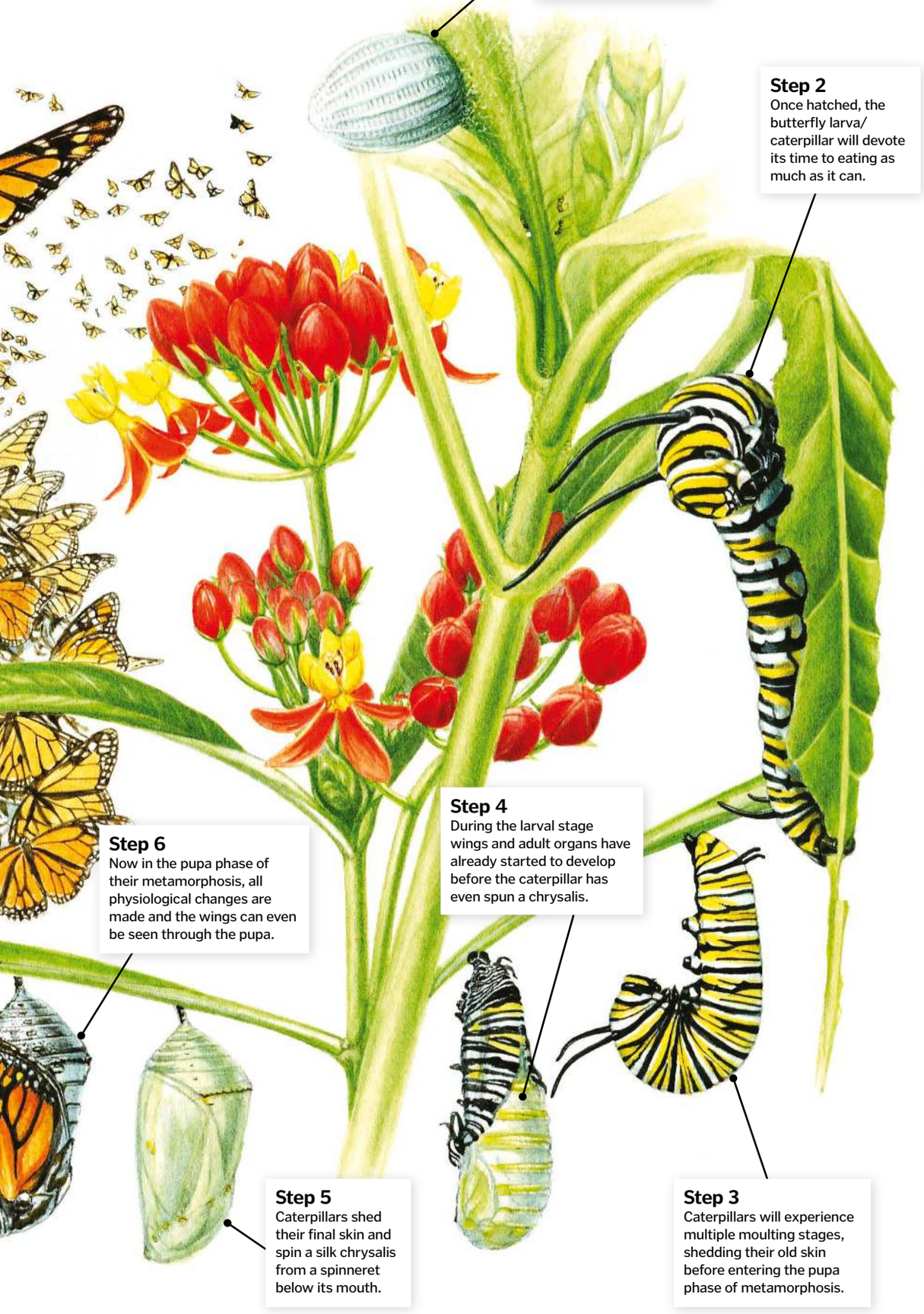
Far from the bright red body of their adult forms, ladybird larvae metamorphosise in a similar way to butterflies

Step 8
Adult monarch butterflies will go on to live another two to six weeks in the summer. Those born later in the year will migrate to warmer climes and live for around six to nine months.

Step 7
Adults break through their chrysalis and unfold their newly acquired wings and transformed body. The butterflies have now completed their transformation and will not grow any bigger.

Monarch metamorphosis

What does it take for caterpillars to become beautiful butterflies?



Step 1
Varying in size and shape depending on the species, cylindrical eggs are placed on leaves.

Step 2
Once hatched, the butterfly larva/caterpillar will devote its time to eating as much as it can.

Step 3
Caterpillars will experience multiple moulting stages, shedding their old skin before entering the pupa phase of metamorphosis.

Step 4
During the larval stage wings and adult organs have already started to develop before the caterpillar has even spun a chrysalis.

Step 5
Caterpillars shed their final skin and spin a silk chrysalis from a spinneret below its mouth.

Step 6
Now in the pupa phase of their metamorphosis, all physiological changes are made and the wings can even be seen through the pupa.

FIVE GREAT... ANIMAL TRANSFORMERS

1 Flat fish

During a flat fish's early stages, its eyes are positioned on either side of its head, but over time one eye will migrate to the other side to form their unique appearance.

2 Lyre bird

These remarkable birds are able to transform their voices to mimic other species, and have even been noted to copy the sounds of car alarms and chainsaws.

3 Arctic fox

In order to blend in, an Arctic fox will change its coat to match its habitat. It will grow a thick white coat in winter, then shed to reveal a thinner, brown coat in summer.

4 Longfin inshore squid

Rather than changing their physical appearance, this species of squid has the ability to edit their genetic code by altering different proteins to suit their changing environment.

5 White-faced scops owl

As a defence mechanism, these small owls can drastically change their appearance to either appear thin and threatening, or puff out to double their size.

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Shaping the shell

How do snails construct their spiral homes?

Snails begin their lives as soft-bodied versions of their future selves in a soft shell known as a protoconch. After hatching from their egg, these tiny gastropods need to protect themselves from curious children and hungry predators by building their hard homes. The foundation to its spiral structure is the accumulation of calcium.

To get the ball rolling on construction, the first source for material lies in their previous residence. Snail eggs are high in calcium, so before searching for leafy greens, snails first eat their own egg to kick-start shell production.

At the mouth of the shell is the mantle, responsible for secreting the shell's building blocks – calcium carbonate. Over time, layered strips of calcium carbonate form the central structure, or ostracum, of the shell.

This layer is sandwiched between the bottom layer, which offers the shells pigment, called the hypostracum, and a coating of an organic skin layer called the periostracum. This final glossy coat is made from proteins called conchiolins, which is similar to the keratin in human hair.

Snails have been used as environmental indicators, as acid rain strips layers off their shells

Colours in the clouds

Discover the science behind the mist-erious spectre phenomenon

Refraction
As the light is broken by the shadow it is not only reflected but also refracted by the water droplets. Acting as a prism, the white (visible) light splits into its component colours.

Shadow
When an object such as a human body or airplane blocks the light a shadow is cast, one that is greatly expanded by the water molecules in the mist.

Antisolar point
This is the point directly opposite to a ray of sunlight. The point needs to be blocked in order to create a Brocken spectre.

Glories in the mist

What are the mysterious Brocken spectres and why do they glow?

Facing the fine rolling mist, those that have reached the summit of a mountain or relaxed in the seat of an airplane may have looked down and witnessed a magnified shadow encapsulated within a rainbow aura. This optical phenomenon is called a Brocken spectre – named after the place where it was first noted at Brocken peak, in the Harz Mountains, in Germany – a spooky silhouette of a spectre surrounded by light emerges among the mist.

The reality of this illusion isn't anything supernatural, but rather the simple combination of direct sunlight and the water molecules in mist, which create a halo-like glory. Glories are a glowing ring of light that surrounds the shadow of objects crossing sunlight under certain misty conditions. These spectres can also be seen through the windows of an airplane, giving its shadow a colourful glow.

Wildlife of the Himalayas

The world's highest mountain range is an unsurprisingly difficult place to live

Nine out of ten of the world's highest mountain peaks can be found in the Himalayas, including the undisputed champion – Mount Everest. This striking mountain range runs for over 2,400 kilometres through Asia and contains a variety of ecosystems full of resilient inhabitants, but its height means that it even has an effect on wildlife elsewhere; the towering mountains divert precipitation, causing monsoons in some areas and helping to produce arid regions like the Gobi and Mongolian deserts.

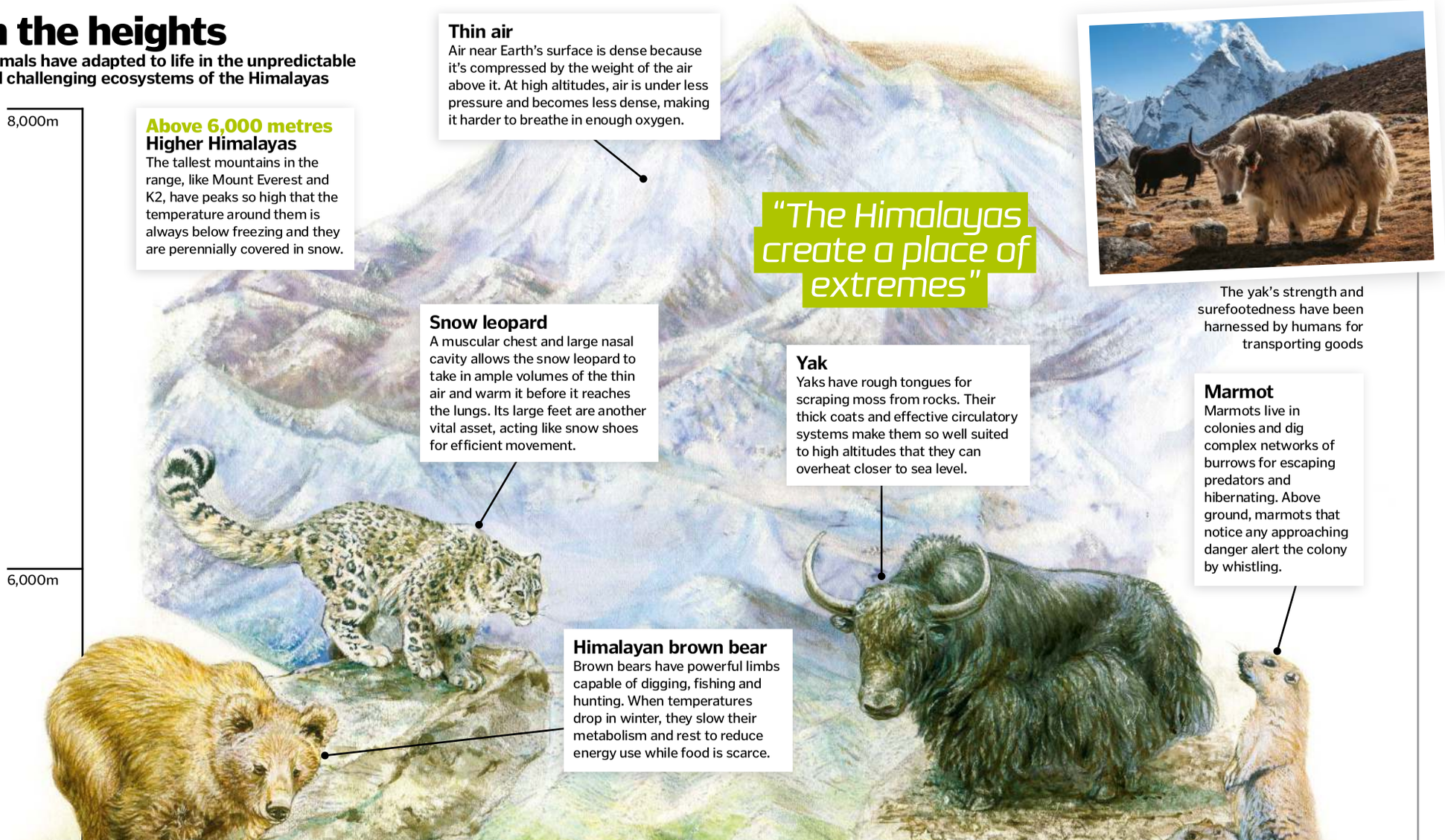
The Himalayas create a place of extremes. In the valleys and foothills summer days can reach 30 degrees Celsius, and average a mild 18 degrees Celsius in the winter. Further up the mountains, it's clear why the range's name comes from the Sanskrit for 'abode of snow' as it's permanently below freezing. Conditions are perilously cold at the summits, with temperatures dropping below -60 degrees Celsius.

From the forests at the base of the mountains all the way up to the sparse, rocky regions near the peaks where plants struggle to grow, the Himalayas provide many different niches that have been filled over time by animals. These species face many challenges, enduring plummeting temperatures, a regular struggle to find food and mates and the need to navigate the tough landscape.

In order to live in such a place, the animals of the mountains have evolved features and behaviours that give them the best chance of survival, like the yak's windproof coat and the marmot's ability to sleep for months at a time.

In the heights

Animals have adapted to life in the unpredictable and challenging ecosystems of the Himalayas



Above 6,000 metres
Higher Himalayas
The tallest mountains in the range, like Mount Everest and K2, have peaks so high that the temperature around them is always below freezing and they are perennially covered in snow.

Thin air
Air near Earth's surface is dense because it's compressed by the weight of the air above it. At high altitudes, air is under less pressure and becomes less dense, making it harder to breathe in enough oxygen.

"The Himalayas create a place of extremes"

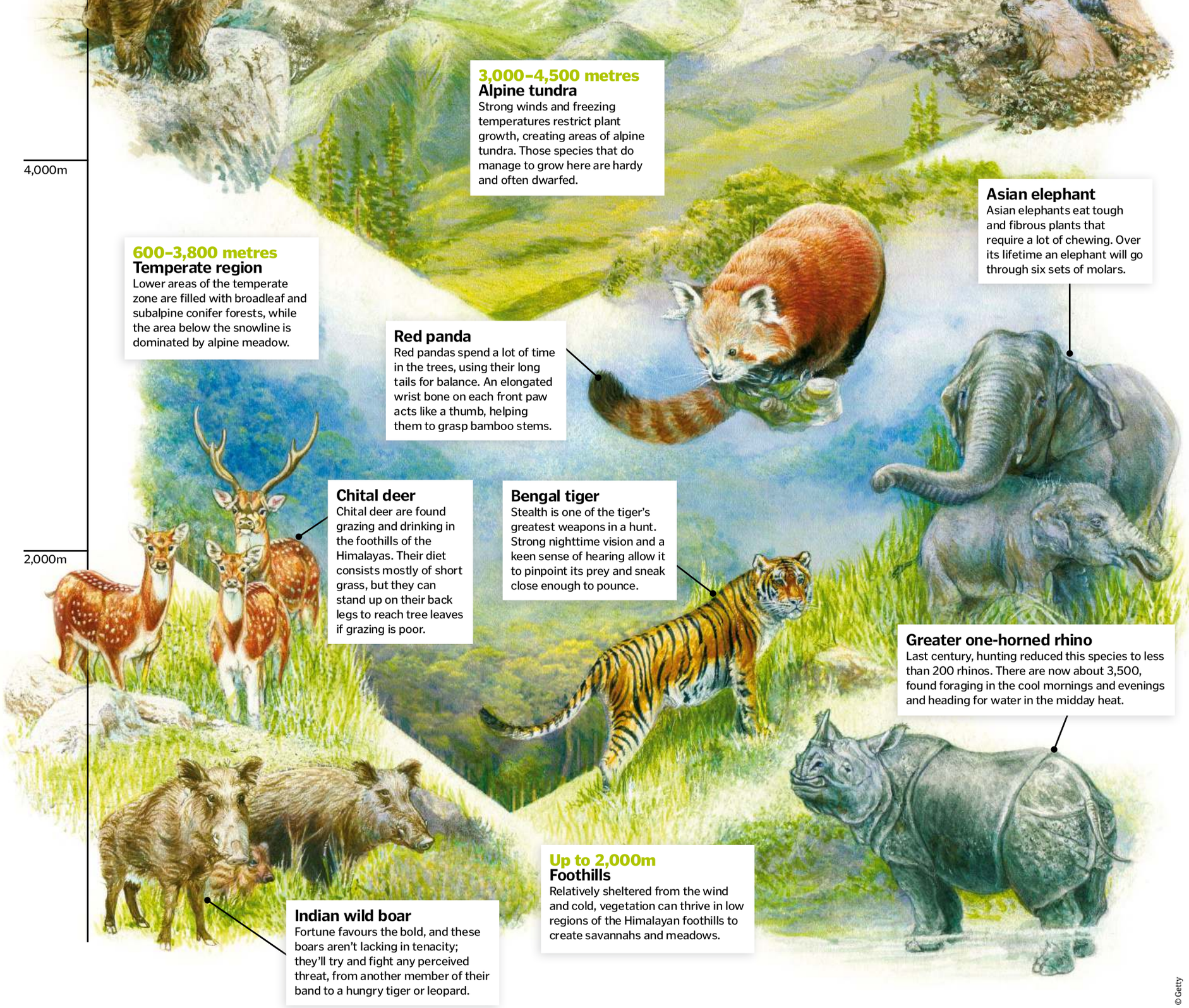
Snow leopard
A muscular chest and large nasal cavity allows the snow leopard to take in ample volumes of the thin air and warm it before it reaches the lungs. Its large feet are another vital asset, acting like snow shoes for efficient movement.

Yak
Yaks have rough tongues for scraping moss from rocks. Their thick coats and effective circulatory systems make them so well suited to high altitudes that they can overheat closer to sea level.

Marmot
Marmots live in colonies and dig complex networks of burrows for escaping predators and hibernating. Above ground, marmots that notice any approaching danger alert the colony by whistling.

Himalayan brown bear
Brown bears have powerful limbs capable of digging, fishing and hunting. When temperatures drop in winter, they slow their metabolism and rest to reduce energy use while food is scarce.

The yak's strength and surefootedness have been harnessed by humans for transporting goods



3,000–4,500 metres
Alpine tundra
Strong winds and freezing temperatures restrict plant growth, creating areas of alpine tundra. Those species that do manage to grow here are hardy and often dwarfed.

600–3,800 metres
Temperate region
Lower areas of the temperate zone are filled with broadleaf and subalpine conifer forests, while the area below the snowline is dominated by alpine meadow.

Red panda
Red pandas spend a lot of time in the trees, using their long tails for balance. An elongated wrist bone on each front paw acts like a thumb, helping them to grasp bamboo stems.

Asian elephant
Asian elephants eat tough and fibrous plants that require a lot of chewing. Over its lifetime an elephant will go through six sets of molars.

Chital deer
Chital deer are found grazing and drinking in the foothills of the Himalayas. Their diet consists mostly of short grass, but they can stand up on their back legs to reach tree leaves if grazing is poor.

Bengal tiger
Stealth is one of the tiger's greatest weapons in a hunt. Strong nighttime vision and a keen sense of hearing allow it to pinpoint its prey and sneak close enough to pounce.

Greater one-horned rhino
Last century, hunting reduced this species to less than 200 rhinos. There are now about 3,500, found foraging in the cool mornings and evenings and heading for water in the midday heat.

Up to 2,000m
Foothills
Relatively sheltered from the wind and cold, vegetation can thrive in low regions of the Himalayan foothills to create savannahs and meadows.

Indian wild boar
Fortune favours the bold, and these boars aren't lacking in tenacity; they'll try and fight any perceived threat, from another member of their band to a hungry tiger or leopard.

DID YOU KNOW? *The Himalayas hold the world's third largest ice and snow deposit after Antarctica and the Arctic*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Ostrich anatomy

Discover the fantastic physiology and amazing abilities of the world's biggest bird

The incredible anatomy of ostriches is one of the most bizarre examples of evolution in the world of birds. There are two species of ostrich: the common ostrich (with four subspecies) and the Somali ostrich. Between them they are the proud holders of several world records, including tallest and heaviest bird and the fastest animal on two legs.

As ostriches are flightless they have evolved to rely on speed to evade predators, but reaching speeds up to 70 kilometres per hour requires a unique skeletal structure. Their legs can measure a dizzying 1.5 metres tall at the hip, with an ostrich's tarsus bones measuring 39–53 centimetres in length. Their long legs and neck mean adult ostriches measure up to 2.7 metres in height and they can weigh up to 145 kilograms. Ostriches have also evolved to have only two toes on each foot (most birds tend to have four) with the large inner toe resembling a hoof, enabling them to run more efficiently. As a result, ostriches can cover a distance of up to five metres in just one stride.

Their compact body, long neck and tiny head may present an odd-looking animal, but these are the traits required to reach and maintain such incredible running speeds. They have developed lightweight and strong pelvic limb muscles comparable to those of similarly fast animals such as horses. Despite being flightless, ostriches' wings play a key role in maintaining balance while sprinting at speed. A combination of all these factors means one thing: ostriches are born to run.

FIVE FACTS

1 Parental instinct
Chicks will run to adults when they feel under threat. This is a good defence mechanism, as an adult ostrich's long, powerful legs have been known to kill lions.

2 Regulating temperature
Like dolphins and pigs, ostriches have no sweat glands. In hot temperatures ostriches rely on panting to cool down without losing important salts from their body.

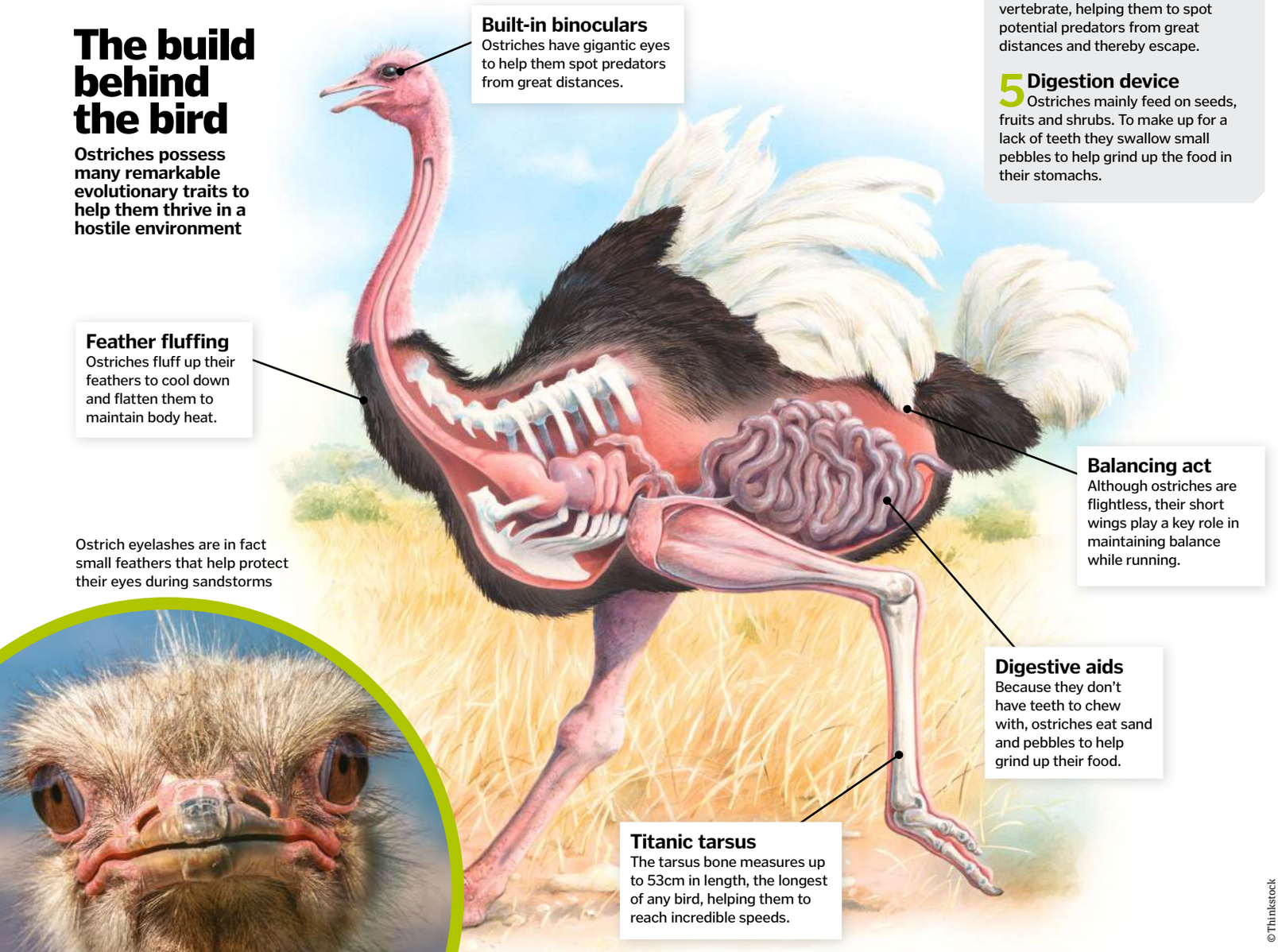
3 The world's largest egg
Ostrich eggs are the largest of any bird. They can weigh up to 1.4 kilograms and measure around 15 centimetres in length.

4 Giant eyes
Ostrich's eyes are the size of billiard balls and are said to be the largest of any land-dwelling vertebrate, helping them to spot potential predators from great distances and thereby escape.

5 Digestion device
Ostriches mainly feed on seeds, fruits and shrubs. To make up for a lack of teeth they swallow small pebbles to help grind up the food in their stomachs.

The build behind the bird

Ostriches possess many remarkable evolutionary traits to help them thrive in a hostile environment



Built-in binoculars
Ostriches have gigantic eyes to help them spot predators from great distances.

Feather fluffing
Ostriches fluff up their feathers to cool down and flatten them to maintain body heat.

Balancing act
Although ostriches are flightless, their short wings play a key role in maintaining balance while running.

Digestive aids
Because they don't have teeth to chew with, ostriches eat sand and pebbles to help grind up their food.

Titanic tarsus
The tarsus bone measures up to 53cm in length, the longest of any bird, helping them to reach incredible speeds.

Ostrich eyelashes are in fact small feathers that help protect their eyes during sandstorms

WELCOME TO THE GREAT EXHIBITION

Prepare to be amazed by the wonders of industry, gathered under one glittering glass roof for the first time in history!

Words by **Jodie Tyley**

Whirring steam engines, a cursed diamond and a controversial statue – these were just some of the curious objects on display at the Great Exhibition of 1851, the first international showcase of inventions and technology. It was such a spectacle that even Queen Victoria was amused, as she wrote in her diary: "The sun shone and gleamed upon the gigantic edifice, upon which the flags of every nation were flying… The tremendous cheering, the joy expressed in every face, the vastness of the building, with all its decoration and exhibits… All this was indeed moving."

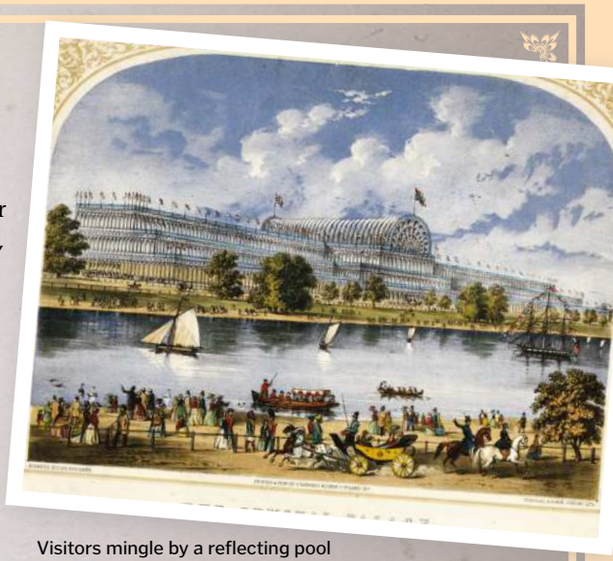
> "The building spanned an area the size of 8 football pitches"

The monarch may have been a little biased, however, as her husband Prince Albert was at the heart of the Exhibition's development. He had become patron of this ambitious project after a civil servant named Henry Cole – the inventor of the Christmas card – convinced him that such an enterprise would be educational and inspirational to the masses. Cole had seen a national display in Paris – the Industrial Exposition of 1844 – and wanted to stage a similar showcase in England. It would be the perfect opportunity to show off the country's achievements during the Industrial Revolution. The Royal Commission for the Exhibition was appointed to make this vision a reality, but an issue soon arose: where would such a grand and extravagant event take place?

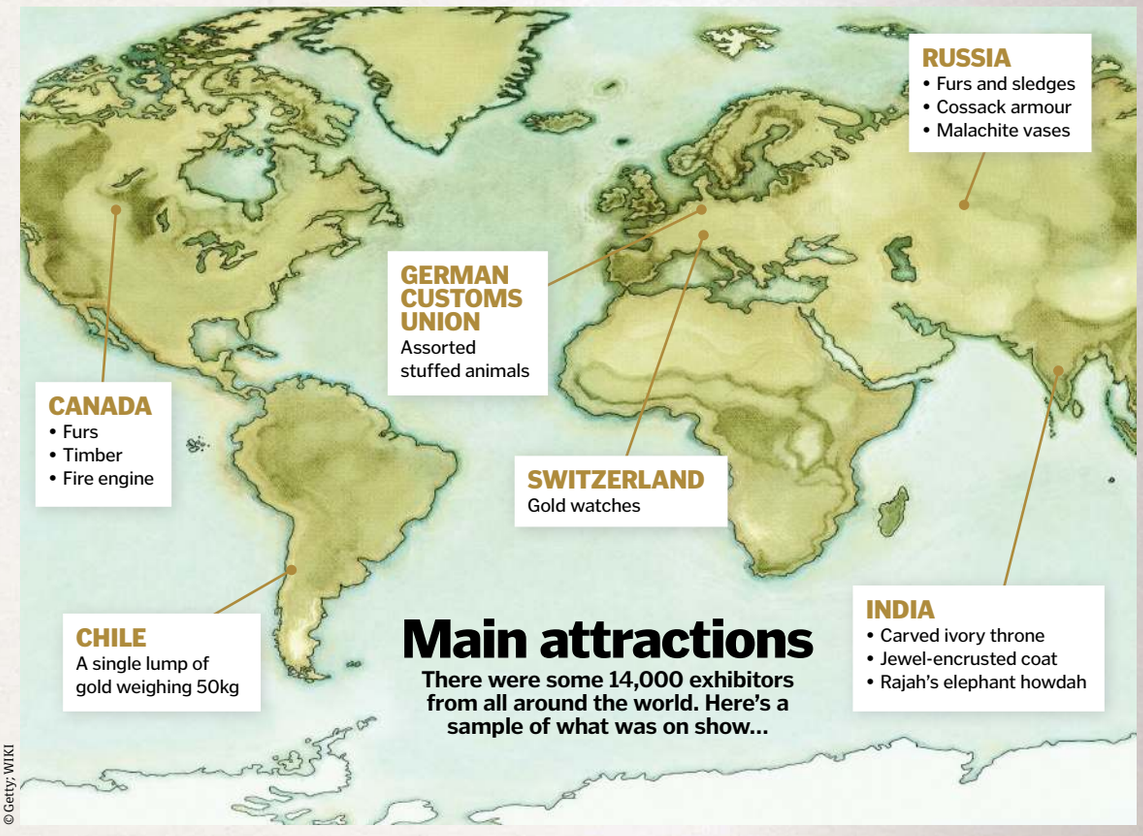
A MATERIAL MARVEL

It seemed that no such place existed, so a competition was launched to design a suitable venue. After more than 200 designs were submitted and rejected, inspiration bloomed unexpectedly. Joseph Paxton was head gardener for the Duke of Devonshire at Chatsworth House, but far from just tending to the grounds, he had designed fountains, a model village and built a conservatory and a lily house that cleverly resembled the leaves of the plant. He proposed a prefabricated structure of cast iron and glass – similar to his lily house but on a much larger scale – that could be assembled in time for the grand opening on 1 May 1851. The idea was greenlit.

London's Hyde Park was transformed into a construction site as work began. Trenches were dug and concrete foundations were laid to withstand the weight of the walls, while underground iron pipes formed the base for columns. Large iron beams (girders) strengthened the structure of the Crystal Palace, so-called because of the sheer amount of glass used. There were approximately 300,000 sheets in the largest size ever made at that time, each measuring 1.3 metres x 25.3 centimetres. In a stunning feat of construction, 80 men worked tirelessly to install more than 18,000 panes of glass in just a single week.



Visitors mingle by a reflecting pool excavated next to the Crystal Palace



Main attractions

There were some 14,000 exhibitors from all around the world. Here's a sample of what was on show…

© Getty; WIKI

TOP FIVE… A-LIST ATTENDEES

1 Charlotte Brontë

The author of *Jane Eyre* enjoyed her visit so much she went more than once, writing, "It is a wonderful place – vast, strange, new and impossible to describe."

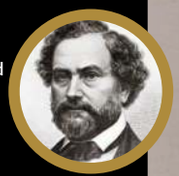
2 Lewis Carroll

The *Alice's Adventures In Wonderland* author must have felt as overwhelmed as his fictional creation. He told his sister the Exhibition "looks like a sort of fairyland."

3 Charles Darwin

Perhaps it's unsurprising that such an inquisitive mind was drawn to The Great Exhibition. Eight years later, he would publish his groundbreaking theory of evolution.

4 Samuel Colt



The American inventor demonstrated his prototype of the Colt Navy revolver, which would go on to become his most famous handgun.

5 Charles Dickens

The famous author co-wrote an article about the Exhibition in which he heralded the machinery on show: "One's head whizzes with the recollection of them." He was particularly impressed by the printing machinery.

8.2m
HEIGHT OF THE GLASS FOUNTAIN INSIDE THE EXHIBITION

6,000,000
THE NUMBER OF VISITORS FROM MAY TO OCTOBER

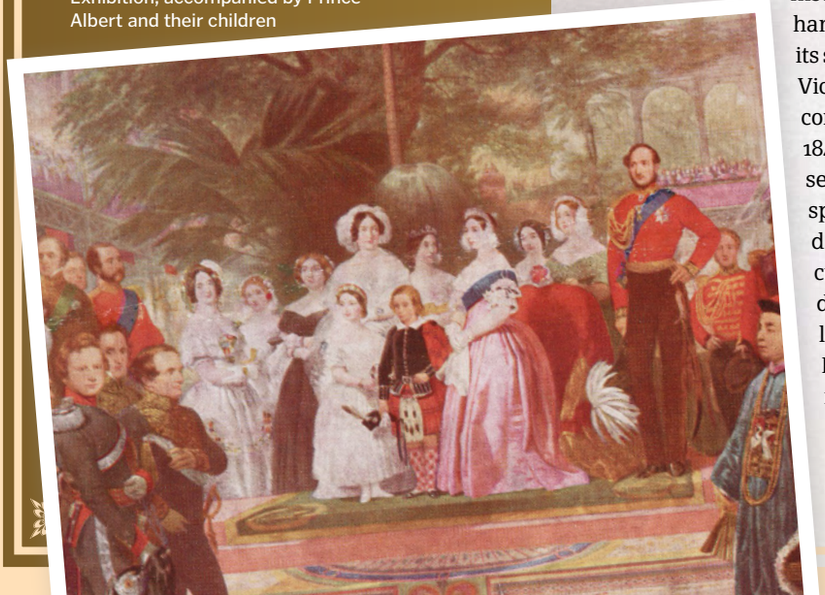
100,000+
OBJECTS ON DISPLAY

164
THE NUMBER OF DAYS THE EXHIBITION WAS OPEN

300,000
PANES OF GLASS USED TO BUILD THE CRYSTAL PALACE

£186K
TOTAL PROFIT FROM THE EVENT

Queen Victoria opened the Great Exhibition, accompanied by Prince Albert and their children



The building materials were manufactured in the Midlands, but the invention of the telegraph meant that communication between the factories and the building site was maintained. These prefabricated parts were then hoisted into position using cranes, so what took centuries to construct with ancient architectural methods took just 22 weeks in the age of steam-powered machines. The building spanned an area the size of at least eight football pitches and towered over 30 metres high so that trees could be left to grow inside the building. It was an engineering marvel, but it was what lay inside that would truly astound.

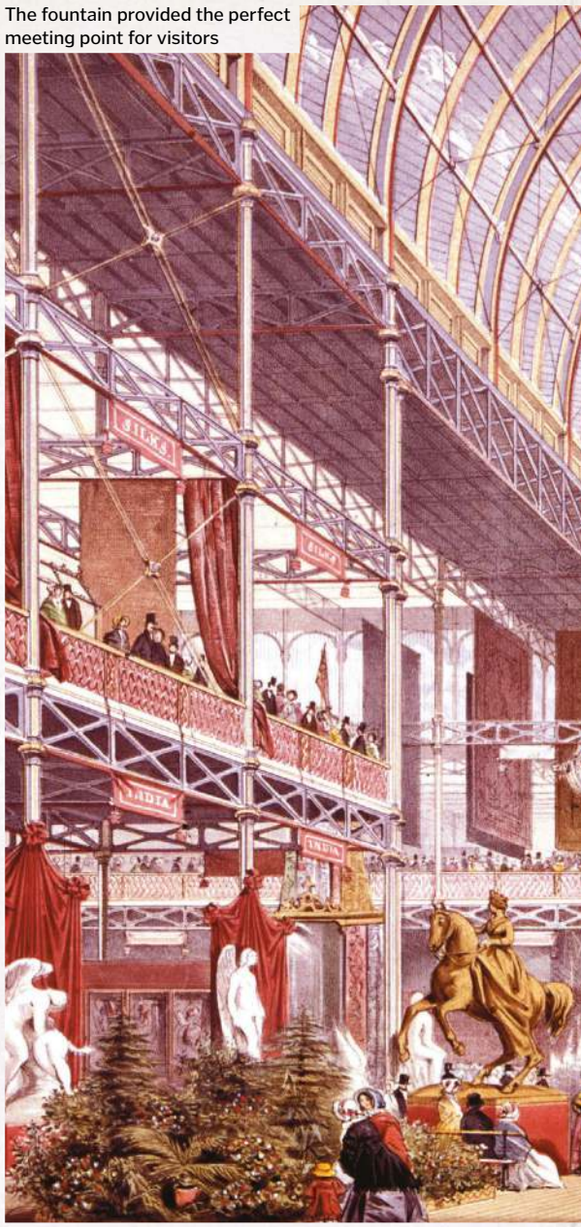
INSIDE THE EXHIBITION

Stuffed kittens taking tea, a folding piano and a lump of solid gold – the exhibition featured more than 100,000 assorted objects. As the host, Britain and her empire filled half the space with manufactured goods, from silk and surgical instruments to a massive hydraulic press that had lifted thousands of tons' worth of metal tubes to build the Britannia Bridge. Among the machinery on display were power-driven looms that spun yarn, industrial cotton-spinners and a printer that could spit out 5,000 copies of the *Illustrated London News* in an hour. Visitors could see the mechanisms at work, a demonstration of British industrial prowess.

Meanwhile, in the other half of the Crystal Palace lay wonders from the rest of the world. France – a force to be reckoned with in the textile market – sent tapestries, silks from Lyon and the finest Sèvres porcelain. The American section was dominated by an eagle and featured Samuel Colt's firearms and Hiram Powers' Greek Slave – a provocative sculpture of a woman wearing nothing but a chain, which attracted much attention despite Victorian attitudes to nudity.

One of the most talked-about objects was the Koh-i-Noor jewel from India. It was thought to be the the world's largest and most valuable diamond in 1851. The gem, marred by its bloody history, had changed hands various times until its surrender to Queen Victoria after the British conquest of the Punjab in 1849. Crowds gathered to see this closely guarded spectacle, but the diamond was inexpertly cut and many were disappointed by the lack of sparkle. When Prince Albert heard the negative reaction, he ordered that the diamond be re-cut.

The fountain provided the perfect meeting point for visitors

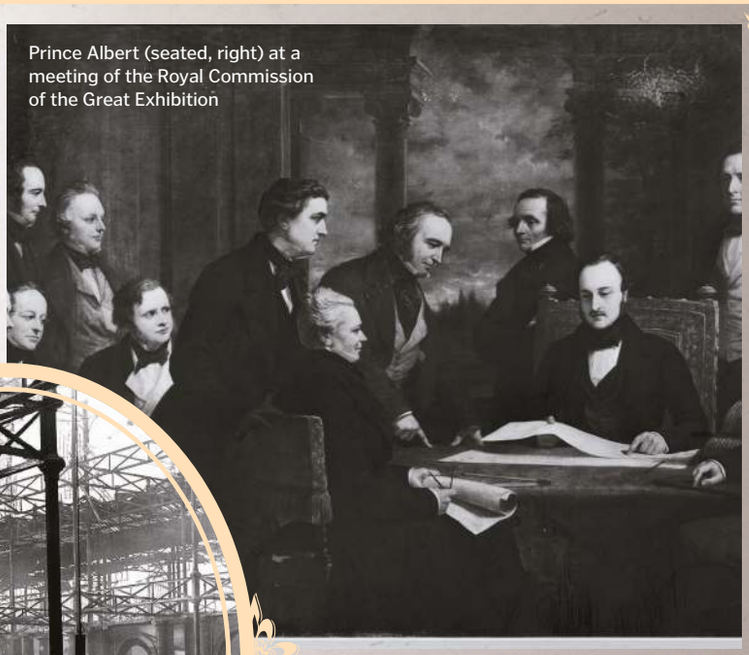


Today, the much smaller but more brilliant Koh-i-Noor can be seen in the Queen Mother's crown on display at the Tower of London.

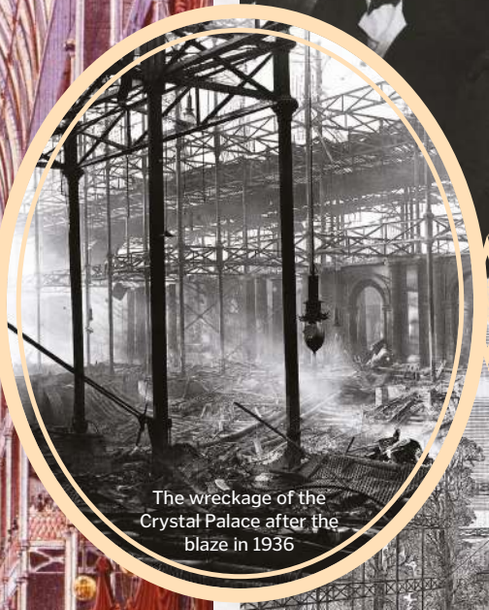
LASTING LEGACY

By the time the Great Exhibition closed in October, over 6 million people had passed through the glass doors. At first, only the wealthy could afford to go, with tickets costing over £3 for gentlemen and over £2 for ladies – over £200 in today's money. However, with the introduction of 'Shilling Days', everyone from factory workers to villagers and school children were able to attend. Queen Victoria was a frequent visitor and watched in delight as visitors poured through the Crystal Palace. She wrote in her diary: "There must have been 120,000, all so civil and well behaved, that it was a pleasure to see them."

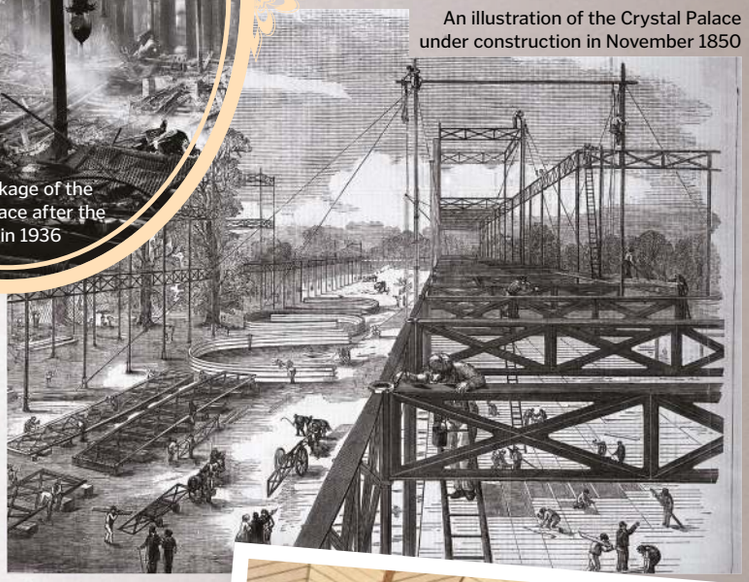
The rich upper class would arrive by carriage, but the most common form of travel was by rail.



Prince Albert (seated, right) at a meeting of the Royal Commission of the Great Exhibition



The wreckage of the Crystal Palace after the blaze in 1936



An illustration of the Crystal Palace under construction in November 1850

© Getty; Alamy

> *"Queen Victoria was a frequent visitor"*

The original Euston station had opened in 1837, linking London with towns and cities in the Midlands and the north. Thomas Cook – the man behind the international travel company – seized this opportunity to sell excursions that included travel and the entrance fee, a huge boon to his growing business.

Despite predicting a loss, the self-financed Exhibition made a staggering profit of £186,000 – equivalent to tens of millions today. The Royal Commission was made permanent in order to spend the money under Prince Albert's orders to "increase the means of industrial education and extend the influence of science and art upon productive industry". Land was purchased in South Kensington and a complex of museums were established: the Victoria and Albert, Natural History and Science museums; the Royal Albert Hall; Imperial College and the Royal Colleges of Art and Music. Even after its founder and president's untimely death, the Royal Commission still worked to fulfil Prince Albert's wishes and used the remaining funds to set up science scholarships to support early career scientists. These Research Fellowships still continue to this day.

As for the Crystal Palace, the building was disassembled and re-erected in Sydenham, where it stood until one fateful night in November 1936. A fire broke out so severe that 88 fire engines weren't enough to save the Palace. There is little left of the original structure, but the lasting legacy of The Great Exhibition ensures that it will inspire and educate for generations to come.

Visitors watched the moving machinery and engines in awe

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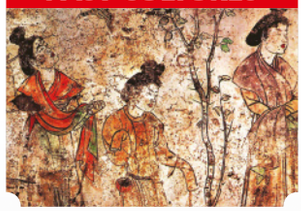

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Post in World War I

How 12.5 million letters reached the front line each week during the Great War

During WWI, letters from home were incredibly important to the millions of British soldiers fighting on the front line. This required a new postal network – stretching across the English Channel and beyond – to cope with the demand. A huge postal depot was built in London to process all of the correspondence.

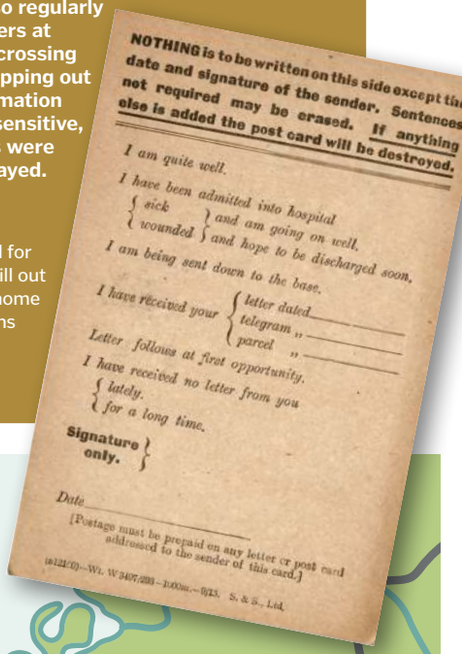
Covering a massive five acres of Regent's Park, the Home Depot sorted through millions of postcards, parcels and letters each week. The depot's 2,500 staff were mostly female, filling many of the roles vacated by men serving in the Army. At the outbreak of the war, about 75,000 General Post Office (GPO) employees were released to fight for their country.

Once out of London, the mail faced the perilous Channel crossing. From February 1915 Germany began a campaign of unrestricted submarine warfare, meaning its deadly U-boats began targeting and sinking Allied shipping. To counter this threat, in 1917, the Royal Navy began using a convoy system to escort and protect merchant vessels making the journey.

Arriving at the main ports of Le Havre, Boulogne or Calais, the mailbags were handed over to the Royal Engineers Postal Section and continued via truck, train or cart to the trenches. Soldiers often received food, clothing, tobacco and other luxuries from home, as well as news. On average, it took two days for letters to reach their destinations, but soldiers' replies were often slower than this due to censorship screening, which was put in place to ensure morale and security were not jeopardised.

Censorship

During the war both sides deployed spies to gather intelligence on troop movements and planned attacks – information that could be unwittingly revealed in letters sent home from soldiers on the front line. Also, the British government wanted to conceal the true horrors of the trenches from the home front wherever possible in order to maintain public morale. Pre-written postcards were supplied to troops, who could delete multiple-choice answers to let family know they were well and to ask about any news from home. Senior officers would also regularly open letters at random, crossing or even ripping out any information deemed sensitive, so letters were often delayed.


NOTHING is to be written on this side except the date and signature of the sender. Sentences not required may be erased. If anything else is added the post card will be destroyed.

I am quite well.
I have been admitted into hospital { sick / wounded } and am going on well.
I am being sent down to the base.
I have received your { letter dated / telegram / parcel }
Letter follows at first opportunity.
I have received no letter from you { lately. / for a long time.
Signature only.
Date
[Postage must be prepaid on any letter or post card addressed to the sender of this card.]

A postcard for troops to fill out and send home with options to delete where necessary

Letters to the front line

The postal network provided a vital connection between serving troops and their families

12.5 million letters left the Home Depot each week.

Home Depot
In December 1914 a huge sorting office was built in Regent's Park, London. Each letter and parcel sent to the front line would start its journey here.

Calais

Boulogne

Le Havre

Train and truck
After arriving in France, the mail would be passed over to the Royal Engineers and continue to its destination either by train or truck, finally arriving two days after leaving London.

A British soldier on the Western Front writes his letter home

Channel crossing
As many as 19,000 mailbags would make the perilous crossing each day, often escorted by convoys to protect against U-boats.

Censorship
Replies from troops were routinely censored to remove sensitive information such as battle plans or even to conceal disturbing descriptions of life in the trenches. At the height of the war, 375,000 letters were censored each day.

The Mausoleum at Halicarnassus

The ancient tomb that was rediscovered between the bricks of a castle

One of the Seven Wonders of the Ancient World, the Mausoleum at Halicarnassus was once the resting place of the king of Caria, a province in the Persian Empire (now Bodrum, Turkey) with Halicarnassus as its capital. Mausolus ruled over the region from around 377 BCE until his death in 353 BCE, after which his wife, Artemisia II, commissioned the construction of what would become their joint tomb.

Greek architects Satyros and Pythius designed the building; leading sculptors Bryaxis, Timotheus, Leochares and Scopas provided decoration; and hundreds of craftsmen worked to create a tomb fit for a king. The monumental structure stood at over 42 metres tall and became known as a 'mausoleum' after the deceased king in whose honour it was built.

The mausoleum stood in all of its grandeur for around 16 centuries, but then a series of earthquakes destroyed its supportive pillars, bringing the roof crashing to the ground. By 1404 CE the towering tomb had been reduced to nothing but its square base, which was covered with stone ruins. However, the fallen stones would still prove useful. In 1522, rumours of a Turkish invasion descended upon Bodrum: the fallen marble from the mausoleum was used to reinforce and fortify Bodrum Castle's walls, and some sculptures were also ground up to form lime for plaster.

Remnants of the once towering tomb can still be seen in between the bricks of Bodrum Castle. Other statues and excavated artefacts are held at the British Museum in London.

Rediscovering an ancient relic

Sir Charles Thomas Newton, a British archaeologist, was the first to unearth the remains of the once giant mausoleum around 1856. Newton noticed that some of the decorations on Bodrum Castle bore a resemblance to those thought to be on the mausoleum, and so the hunt began.

By studying works by writers of the time, Newton was able to pinpoint the location where it would have stood, which we now know to be Bodrum in Turkey. After purchasing the potential plot of land for the mausoleum, Newton excavated tunnels to surrounding areas and discovered stairs, walls and corners belonging to the legendary structure.

Further excavation led to the discovery of sculpture remains, including the wheel from the roof chariot and the statues of both Mausolus and Artemisia, confirming the site's ancient past.

Ruins of the once towering tomb can still be seen in modern-day Bodrum

Breaking down the mausoleum

How would this highly decorated piece of architecture have looked during its prime?

Greek statues

Marble statues of Greek gods and goddesses were erected around the mausoleum, including the Sun god Apollo.

Hilltop

Built on top of a hill in the ancient city of Halicarnassus, the mausoleum could be seen for miles around.

An ancient giant

The entire structure of the mausoleum reached above 42m and was surrounded by a courtyard with warrior statues stationed at each corner.

Marble Mausolus
Stood at the top of the mausoleum were huge marble statues of Mausolus and Artemisia riding in a four-horse-drawn chariot (quadriga).

Pillars
36 stone columns made up the mid section of the mausoleum, which also supported the 24-step pyramidal roof.

Carvings
At the base of the mausoleum, the stone was decorated with relief sculptures depicting different battle scenes between the Greeks and Amazons.

THE OTHER WORLD WONDERS

1 Great Pyramid of Giza
The oldest and only remaining intact ancient wonder, the Pyramid of Khufu was built some 4,500 years ago.

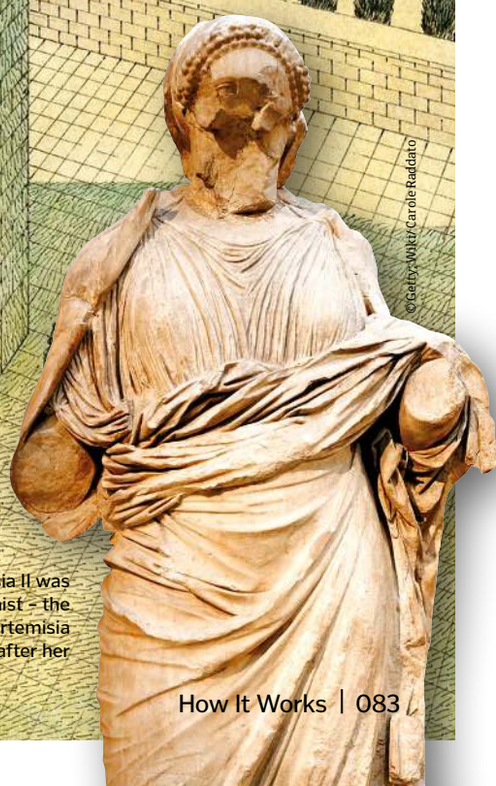
2 Hanging Gardens of Babylon
Constructed under the orders of the Babylonian king Nebuchadnezzar II around 600 BCE, the gardens sat near the Euphrates River in what is now the city of Hillah in central Iraq.

3 Statue of Zeus at Olympia
Created by Greek sculptor Phidias around 430 BCE, this 12-metre-tall statue was plated with gold and ivory and resided in the Temple of Zeus.

4 Temple of Artemis at Ephesus
Constructed around the mid-6th century in what is now Turkey, this building was a place of worship to the Greek goddess Artemis.

5 Colossus of Rhodes
Erected around 280 BCE, the bronze figure of the Greek god Helios stood around 30 metres tall until an earthquake brought him to his knees just 60 years later.

6 Lighthouse of Alexandria
Designed by Greek architect Sostratos around 270 BCE and said to be some 115 metres tall, this majestic tower sat on a small island called Pharos near the harbour of Alexandria.



Queen Artemisia II was also a botanist – the plant genus Artemisia is named after her

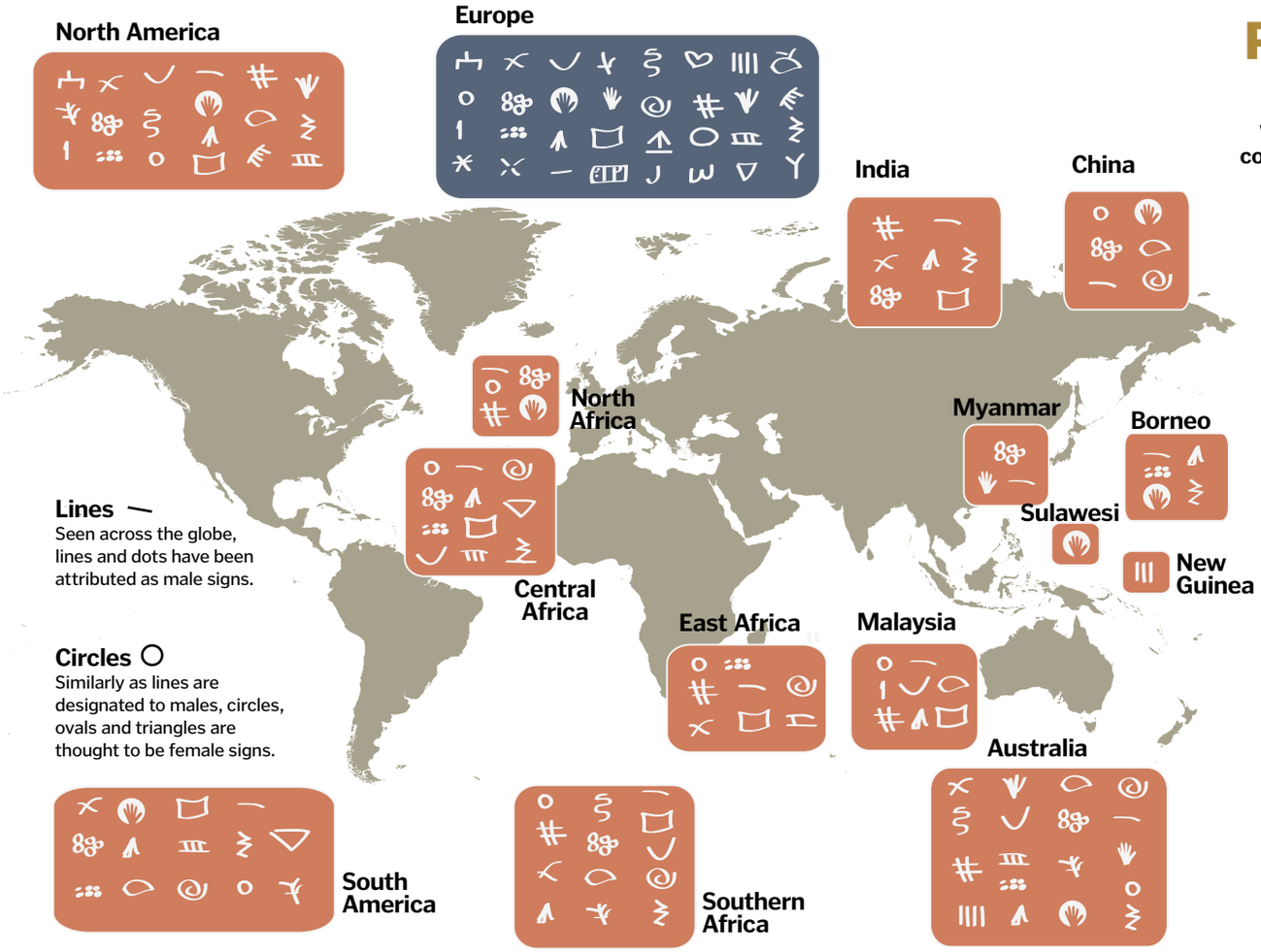
Stone Age doodles

Cracking the code of an ancient communication system

The first known writing system is the 5,000-year-old cuneiform script of Mesopotamia, an ancient region located in what is now Iraq. But this scripture didn't just appear; the written word is thought to have developed from a series of lines, shapes and symbols now called geometric signs.

Palaeoanthropologist Genevieve von Petzinger identified just 32 signs seen in caves across Europe over a 30,000-year time span during the last ice age. Doodling on a notepad can result in many different designs each time you pick up a pen, so discovering only 32 signs reoccurring across Europe cannot be a coincidence, but is more likely to be the beginnings of formal written communication in the ancient world.

Accompanied by the more commonly studied images of bison and hunters, many have speculated each sign's meaning, however, a Stone Age dictionary is still very much in the works.



Lines —

Seen across the globe, lines and dots have been attributed as male signs.

Circles ○

Similarly as lines are designated to males, circles, ovals and triangles are thought to be female signs.

Prehistoric patterns

While distributed across continents, these symbols share many similarities

Origins

It is thought that, as humans moved out of Africa to Europe, Asia and the rest of the world, they continued to use and develop some of these signs.

French figures

The penniform (feather-shaped) sign first appeared 28,000 years ago in France. Its use later spread to southern countries such as Spain.

Global similarities

Cave art examples from across the world show that some of the same signs were widely used. Handprint or hand stencil symbols, for example, have been found on every inhabited continent.

The first instruments

How did our ancient ancestors make music?

The earliest example of a musical instrument is a 40,000-year-old bone flute that was discovered in a cave in south Germany. These prehistoric pipes are so-called because they were often made from bird bones, which are hollow. This property helps reduce birds' body weight for flight, but it also means the bones are ideal for making woodwind-style instruments.

The first bone flute once belonged to the skeleton of a griffon vulture that most likely had died, decomposed and left its bones for a caveman to stumble across. Simple stone tools allowed early humans to carve through the bone and make a sequence of holes along the length of the flute. V-shaped notches were cut at the end, presumably for the musician to blow through.

As the flute developed so too did its source material. Evidence of flutes handcrafted from mammoth tusks has been unearthed. To recreate the natural hollowing of bird bones, tusks were split in two, hollowed out and sealed back together.

It is still unclear what first inspired humans to craft these musical creations

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BRAIN DUMP

Because enquiring minds need to know...

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MEET THE EXPERTS

Who's answering your questions this month?

Laura Mears

Laura studied biomedical science at King's College London and has a master's from Cambridge. She escaped the lab to pursue a career in science communication and also develops educational video games.

Alexandra Franklin-Cheung

Having earned degrees from the University of Nottingham and Imperial College London, Alex has worked at many prestigious institutions, including CERN, London's Science Museum and the Institute of Physics.

Tom Lean

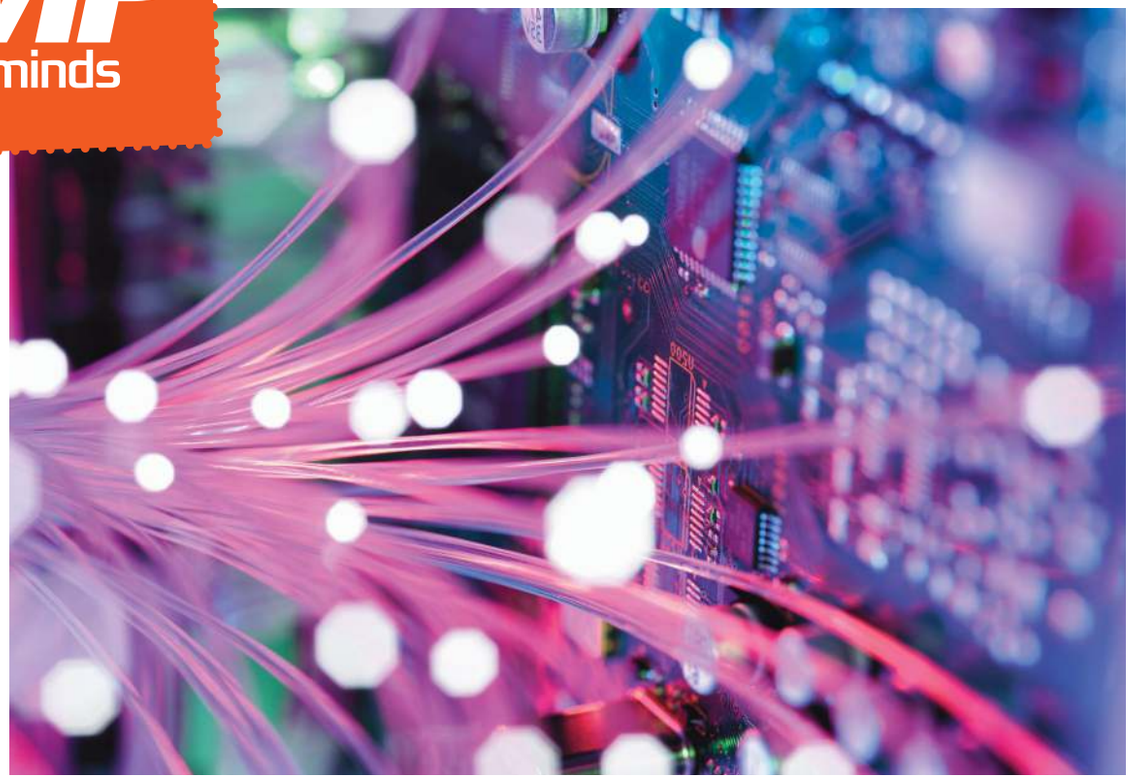
Tom is a historian of science at the British Library, where he works on oral history projects. He published his first book, *Electronic Dreams: How 1980s Britain Learned To Love The Home Computer,* in 2016.

Katy Sheen

Katy studied genetics at university and is a former **How It Works** team member. She now works for a biomedical journal, where she enjoys learning about the brilliant and bizarre science of the human body.

Joanna Stass

Having been a writer and editor for a number of years, **How It Works** alumnus Jo has picked up plenty of fascinating facts. She is particularly interested in natural world wonders, innovations in technology and adorable animals.



Fibre optic cables use light to transmit information quickly and efficiently

How do fibre optic cables transmit data?

Adam Lee

Fibre optic cables transmit data as pulses of laser or LED light. Each cable is composed of thin strands (fibres) of purified glass, which are coated in a reflective glass cladding. This allows a light beam shone into the fibre to travel down its length, bouncing off the walls as it goes. Fibre optic cables can carry far more information than ordinary copper cables of the same thickness, with less signal loss and no interference. AFC

How do bikes stay upright?

Colin Robinson

There is no definitive explanation of a moving bike's tendency to stay upright. For a long time it was believed that the bike's wheels created stability through the gyroscopic effect: the tendency for a spinning object to resist movement in certain directions. A second idea was that the direction of travel aligns the bike's wheels, a bit like when you're pushing a shopping cart. However, researchers disproved both theories in 2011 by building a bike that negated both effects. Many scientists now believe that the small adjustments to steering made (often subconsciously) by cyclists can better explain a moving bike's stability. AFC

The secret to a moving bike's stability remains a mystery

How come some people are lactose intolerant?

George Nelson

People with a lactose intolerance cannot digest lactose, a type of sugar mainly found in milk and other dairy products. This is usually because their digestive system does not produce enough lactase, an enzyme that breaks down lactose into other types of sugar in the small intestine so that it can be absorbed into the bloodstream. JS

Smart thermostats are designed to help reduce your energy bills

How do smart thermostats work?

Eddie Lucas

Instead of a traditional panel on the wall, a smart thermostat is controlled from an app on your smartphone or tablet. The smart thermostat is wired into your boiler via a normal thermostat and also connected to your home Wi-Fi network. This allows you to communicate with the system remotely, so you can turn your central heating on or off from outside the home. Although this is useful in itself, many of the apps have extra features that help save energy and cut bills. For instance, some apps can detect when there is no one at home and turn the heating off for you to avoid waste. KS

What is the difference between a possum and an opossum?

Miriam Bareli

Possums and opossums are both marsupials, but they are actually only distantly related. Possums are native to Australia and some of its surrounding islands, while opossums (pictured) are native to North America, making them the only marsupials that live outside of Australia or its surrounding islands. Confusingly, opossums are sometimes referred to as 'possums' in the US. KS

Does the Sun spin?

Joel MacKay

The Sun does spin, but its rotation rate varies in different places as it's gaseous. At the equator the Sun takes 24.47 days to rotate but up to 38 days near the poles. TL

Why do potholes form in roads? Corey Grant

Potholes happen when water seeps through cracks in the road surface and into its base. The water erodes the roadbed, particularly in winter when ice forms and expands, gradually forming a gap under the road. When traffic drives over it, the road surface collapses into the gap, forming a pothole. TL

When was Morse Code first developed?

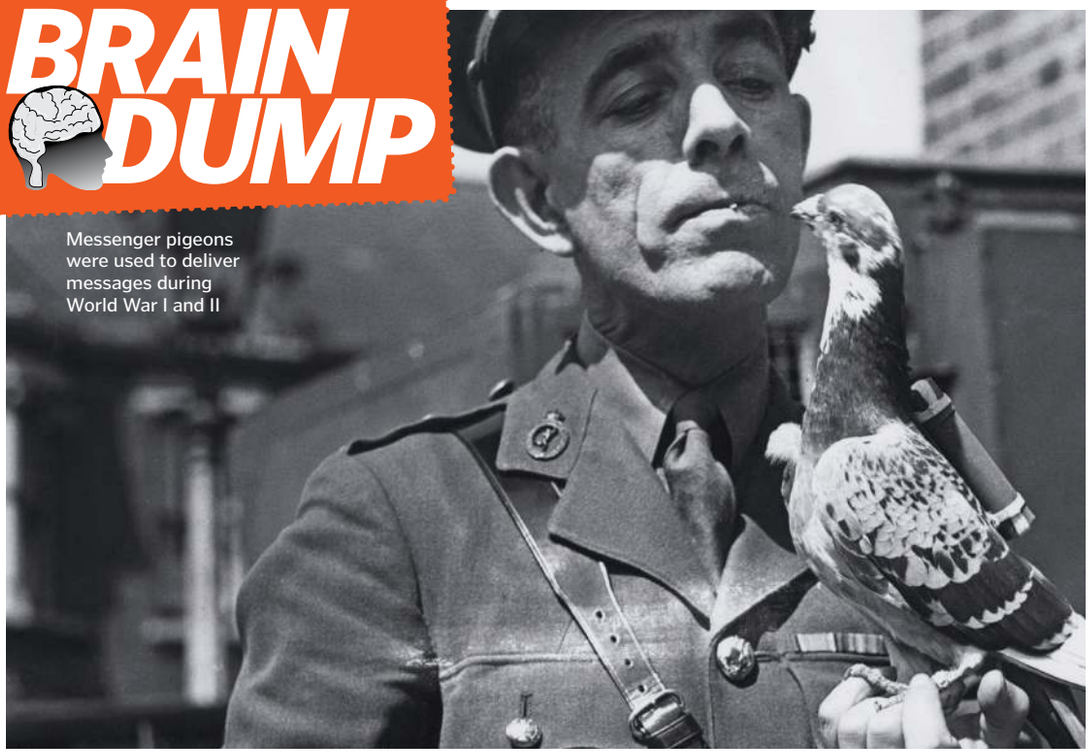
Laura MacArthur

This method of communicating with dots, dashes and spaces was invented by Samuel F B Morse in the 1830s, but the system was developed and improved to become International Morse Code in 1851. KS

Why are different periods of history known as the Stone, Bronze or Iron Age? Lottie Sykes

The names correspond to the materials used by people living at the time. At first, people made tools with flint, stone and bone. Then they started forging metals, first bronze and then iron. LM

BRAIN DUMP



Messenger pigeons were used to deliver messages during World War I and II

What's the difference between carrier and messenger pigeons?

Sally Baker

■ Carrier and messenger pigeons are both species descended from the rock pigeon. Carrier pigeons are bred as ornamental birds by pigeon fanciers and have a fleshy growth on the top of their bill called a wattle-cere. Messenger pigeons, also known as homing pigeons, are bred for their ability to find their way back home and travel quickly over long distances. They were once used to deliver urgent messages, especially in times of war, but today they are more commonly used for pigeon racing. JS

Why shouldn't you store bananas with other fruit?

Joan Rowland

■ As they ripen, bananas release a gas called ethene, also known as ethylene, which is a natural plant hormone. It causes ripening by breaking down cell walls, converting starches to sugars and reducing the fruit's acidity. Some other fruits, including apples and pears, also give off and are susceptible to the effects of ethene, so storing them together can speed up ripening, causing the fruit to turn soft and brown more quickly. However, some fruits, including oranges, lemons and many berries, do not give off or respond to ethene so will not ripen prematurely when stored near other fruit. JS

Only store bananas, apples and pears together if you want them to ripen quickly

How many galaxies are there? Jimmy Cunningham

There are 2 trillion galaxies in our universe according to the latest analysis of Hubble data. 90 per cent of these are too far away or too faint to be seen with existing telescope technology. AFC

Why do fans cool us down?

Peggy Faris

By helping air circulate, fans make it easier for sweat on your skin to evaporate and for hotter air around your body to dissipate. This wind chill effect makes you feel cooler, although the temperature in the room stays the same. AFC

When was the Hollywood sign put up? Sigourney Farrah

The sign was erected in 1923 to advertise *Los Angeles Times* publisher Harry Chandler's upscale real estate development 'Hollywoodland'. The 'land' was removed when it was refurbished by the Hollywood Chamber of Commerce in 1949. JS

Does exercise reduce stress?

Jimmie Edwards

Yes, physical activity changes your sense of well-being. Exercise raises levels of the body's natural painkillers, known as endorphins. It also reduces stress hormones like adrenaline and cortisol. It can help to improve body image too. LM

There are often speed limits on aircraft flying near airports

Do commercial airliners have to obey speed limits in the sky?

Sonia George

There are speed limits on airliners, but these vary depending on how high and where they are flying. For example, if flying under 3,000 metres airliners are often limited to 463 kilometres per hour. Speed limits around busy airports are lower. In some places, like flying at high altitude over the ocean, there is no legal speed limit, but the airliner's manufacturer will have set a maximum speed that the pilot is forbidden to exceed to avoid damaging the aircraft. TL

Is turmeric really good for you?

Franki Clamenza

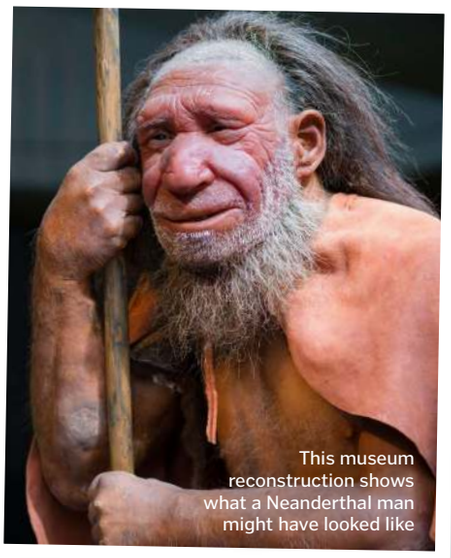
Turmeric contains a chemical called curcumin, which has recently been in the headlines for its health benefits, such as reducing the risk of Alzheimer's disease, arthritis and diabetes. However, many studies showing the effects of curcumin have only been conducted on animals. Although these have shown some promising results, we do not yet know whether the results apply in humans or how much turmeric we would need to eat to see any benefits. More tests are required. KS

The Chubb brothers produced the first line of safes in 1835

How do safes work?

Izzy Pascal

Safes are often sealed by a combination lock. Inside there is a 'pack' of wheels, each with a notch. They sit on a spindle, which feeds into the dial on the outside of the safe. At the back there's a drive cam, which turns with the dial. A pin on the drive cam catches a bump, called a fly, on the first wheel, turning them together. A pin on the first wheel 'picks up' the fly on the next wheel and so on. To unlock the safe you need to turn the wheels back and forth in the right combination so that their notches all line up. When this happens, a piece of metal called the fence drops down and the lock will open. LM



This museum reconstruction shows what a Neanderthal man might have looked like

Did Neanderthals and Homo sapiens live together?

Amelia Holloway

Our cousins, *Homo neanderthalensis*, lived between 400,000 and 40,000 years ago. Like us, they came from Africa, but by the time modern humans first appeared around 200,000 years ago, they had already moved to Europe. Modern humans didn't follow them north until around 45,000 years ago and, within 5,000 years, the Neanderthals had all but disappeared. However, genetic evidence suggests that this short overlap gave our two species enough time to interbreed. LM

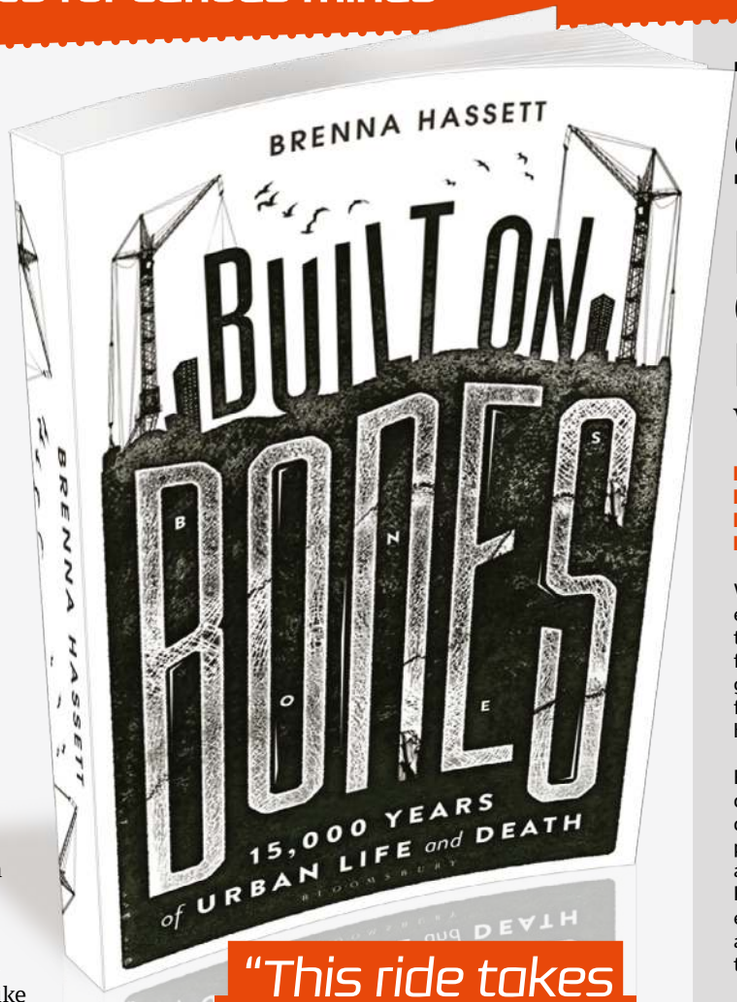
What is a flywheel?

Adam Grace

A flywheel is a mechanical device for storing energy. If you were to take a heavy metal wheel on a shaft and spin it around really fast, the wheel would carry on spinning for some time after you'd stopped spinning it as it has built up a store of kinetic energy through the wheel's momentum. This energy can be used to power other devices, such as buses, sewing machines, electrical dynamos and even industrial machinery. Although some of its energy will be lost to friction, a modern flywheel is often sealed in a vacuum and uses magnetic bearings to keep friction to a minimum, making it a very efficient mechanical battery. TL

BOOK REVIEWS

The latest releases for curious minds



Built on Bones

Life and death in the cities of the world

- Author: **Brenna Hassett**
- Publisher: **Bloomsbury Sigma**
- Price: **£16.99 / $27**
- Release date: **Out now**

We'll admit to being slightly hesitant when first opening *Built on Bones*, a book that promised an analysis of "15,000 years of urban life and death". It doesn't sound like the most uplifting of topics, after all. Thankfully, Brenna Hassett's paleoarchaeological trip through the ages is upbeat, pacey and will often raise a smile as you speed through the many topics it covers.

Rather than pure science, this ride takes regular detours into pop culture, personal accounts of worldwide trips and opinions on the modern world. The result is a book that, while rammed full of interesting facts (did you know that leprosy can still be detected in ancient skeletons because it changes the way the arms and legs move?) also manages to strike a conversational, entertaining tone that remains engaging throughout.

Of course, there's plenty of science packed in there as well, and as always, it's wonderful to read about a scientific field when it's written about well by someone who *really* knows their stuff. When Hassett is explaining, in detail, the specifics of a find, what makes it significant and what it can tell us about the past, it's hard to put the book down. Revelations about how different diseases, many of which only affect muscles, skin or nerves, can change the skeleton in a way that can be detected thousands of years later, will inevitably become facts you later share with your friends and family members just to watch their amazement.

> *"This ride takes detours into pop culture and the modern world"*

Of course, it's expanding these microscopic findings into an analysis of how cities affected the human race that's the real challenge. While there are some questions that can't be completely answered, Hassett does well here too. From discussing how cities and trade routes could spread diseases more easily, to how large settlements may have reduced the number of violent deaths, the book navigates these challenges with aplomb, even explaining how tiny indents in a skull can tell us a lot about the differences human cities have made.

It might not be to everyone's taste, but thanks to a pithy, engaging writing style and some real technical skill, *Built on Bones* manages to make a book about death and skeletons not only readable but entertaining, and we really weren't expecting that.

★★★★☆

To the Ends of the Earth: The Truth Behind the Glory of Polar Exploration

Voyages of the damned

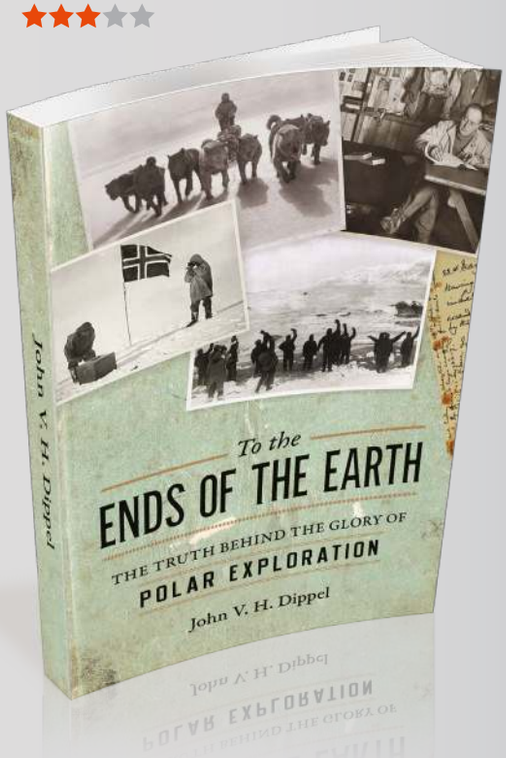
- Author: **John V H Dippel**
- Publisher: **Prometheus Books**
- Price: **£22.50 / $28**
- Release date: **Out now**

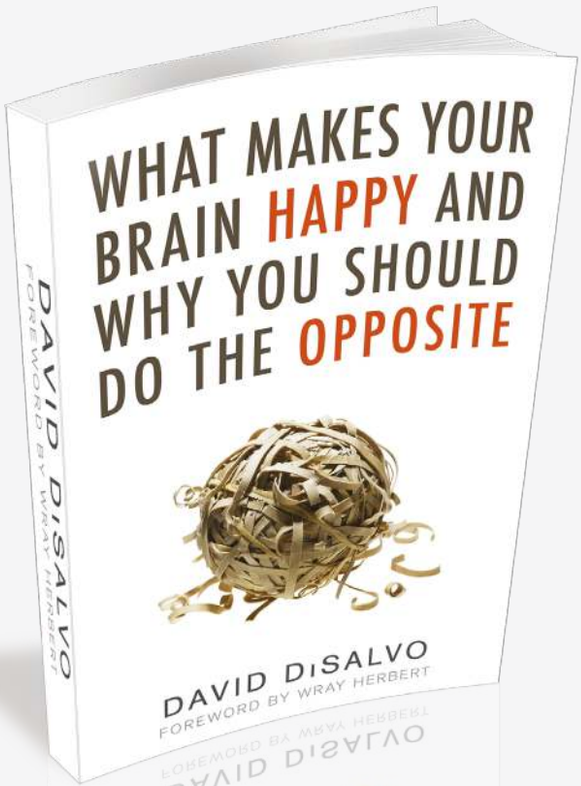
When you think of the snow-chasing Arctic explorers of yore, the common perception of their escapades is a rose-tinted one: of intrepid, fearless pioneers jumping into what was then a great unknown, risking life and limb (hello frostbite) in a bold effort to further the limits of human understanding.

There are few heroes in this book, however. Rather, John V H Dippel expounds a more damning outlook of individuals using the public's desire for hero figures to mask their own personal ambitions while displaying a cold ambivalence about putting lives in harm's way. From Robert F Scott's ill-fated voyage to explorers' less-than-complimentary accounts about the native Inuits, there's little romanticism to be found here.

While its outlook is made clear from the off, accusations of authorial bias will likely follow this, unfairly or otherwise. Whether all the character traits Dippel views as negative are indeed so will depend on your own opinions, but that they pose food for thought can't be denied.

★★★☆☆





What Makes Your Brain Happy and Why You Should do the Opposite

How your mind's delusions affect you

- Author: **David DiSalvo**
- Publisher: **Prometheus Books**
- Price: **£15.99 / $18**
- Release date: **Out now**

Broadly expounding on the mantra that the easiest decision isn't necessarily the correct one, renowned science writer David DiSalvo takes this further, applying a variety of evolutionary, psychological, neurological and even economic considerations to the titular proposition.

Doing this for a species that conducts such irrational activities as warfare, polluting much of its natural habitat and watching rubbish TV could very well be considered a thankless task, yet DiSalvo makes a decent fist of pushing his case. From the prevalence of compulsive disorders and transactive memory (those annoying couples who finish each other's sentences) to the ability to cast doubt on people's revelations, 100 little things you wouldn't have previously considered as noteworthy suddenly take on a new significance.

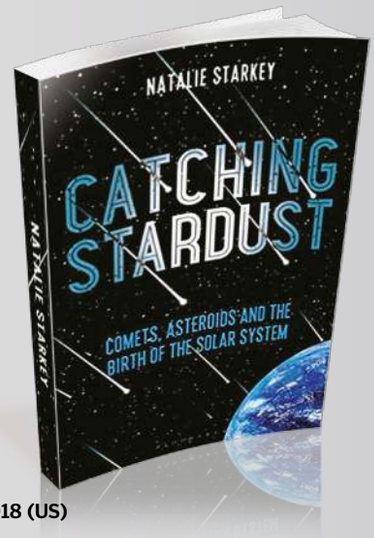
It's inevitable that some will scoff at this due to its unfortunate resemblance to a self-help book. However, look beyond the exterior and there's far more to it – just like life come to think of it.

★★★★☆

"100 things you wouldn't have considered important take on a new significance"

Catching Stardust: Comets, Asteroids and the Birth of the Solar System

Space rocks



- Author: **Natalie Starkey**
- Publisher: **Bloomsbury Sigma**
- Price: **£16.99 / $27**
- Release date: **Out now (UK) / 5 June 2018 (US)**

In much the same way that geology has allowed us to learn more about the history of our own planet, so too do asteroids, comets and other space detritus hold the potential to deepen our understanding of not just our own Solar System, but what lies beyond.

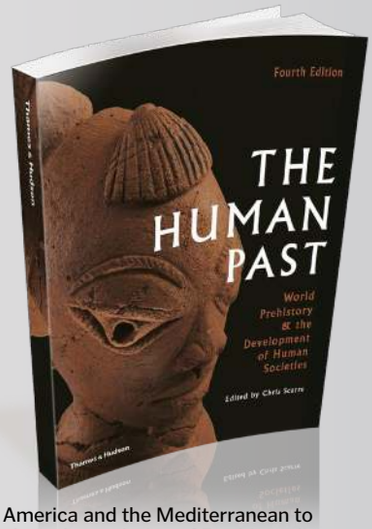
With manned travel to Mars and our other neighbouring planets still out of reach, these relatively more easily attainable materials provide potential opportunities, which Natalie Starkey holds particular focus on, along with the processes for extracting them and the secrets they could unlock. It's all brilliantly accessible, starting by detailing exactly what comets and asteroids are (you'd be surprised at the details that people get wrong), before moving onto topics like possible extraction methods and future missions.

Both highly informative and intriguing, Starkey successfully crafts an engaging narrative while delivering a bus-load of trivia in an engaging and accessible manner. This is definitely one for geologists and future spacefarers alike.

★★★★★

The Human Past: World Prehistory and the Development of Human Societies

Before time itself



- Author: **Chris Scarre (editor)**
- Publisher: **Thames and Hudson**
- Price: **£45 / (approx. $100)**
- Release date: **Out now**

Mention 'prehistory' and images that commonly spring to mind are of dinosaurs, woolly mammoths and Neanderthals. As far as teaching in schools goes (at least the schools we went to) it seems a neglected subject matter, especially considering the historical importance posed by the early formation of human society.

The fourth edition of *The Human Past* is the perfect textbook for those who wish to study this bygone era in more detail, journeying through the likes of Egypt, Asia, Central and South America and the Mediterranean to chart the evolution of Earth's earliest civilisations through the Ice Age and into the first instances of warfare, settlement and more.

Accompanied by a series of images and diagrams that serve to make the subject matter that bit more attainable, this is the kind of book we wish we'd had as youngsters. The steep price may understandably put some off, but any teachers reading this should take note.

★★★★☆

BRAIN GYM

GIVE YOUR BRAIN A PUZZLE WORKOUT

Wordsearch

V	E	Z	P	E	C	S	L	A	I	R	T	F	E	M
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FIND THE FOLLOWING WORDS...

ASTEROID
CHRYSALIS
DEJAVU
DHOW
EXHIBITION
EXTREMESPORTS
FRAGMENT
HERNIA
HIMALAYAS
IMAC
MARS
MAUSOLEUM
PAPER
SIMULATION
SPECTRE
SUPERSONIC
TIME
TRIALS

Quickfire questions

Q1 Which was not an event in the 2018 Winter Olympics?

- Speed skating
- Freestyle skiing
- Ice hockey
- Alpine parkour

Q2 The density of water is...

- 10g/cm^3
- 1g/cm^3
- 1g/cm^2
- 100kg/m^3

Q3 The speed of sound in dry air at room temperature is...

- ~580m/s
- ~1,645m/s
- ~340m/s
- ~85m/s

Q4 The original Crystal Palace was first located in...

- Hyde Park
- Sydenham Hill
- Regent's Park
- Kensington Gardens

Spot the difference

See if you can find all six changes we've made to the image on the right

Sudoku

Complete the grid so that each row, column and 3x3 box contains the numbers 1 to 9.

EASY

4	3		9		2		8	
	5			1		4	2	
2	1				8			
8		5			6	2	9	
	9	4				7		3
3				9	1	8	5	4
7				8			1	2
5		1		7	3			
6	2	9		5	4			8

DIFFICULT

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	4		1					
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	5					1		6
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8					7			
3				9				8

What is it?

A .....

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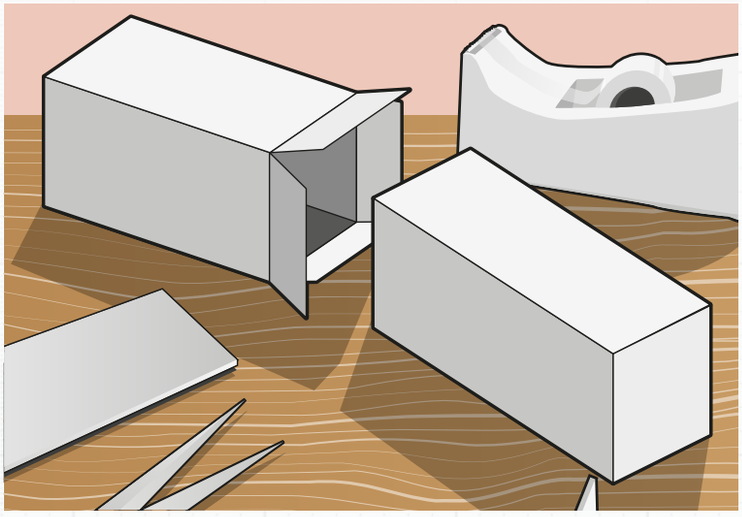
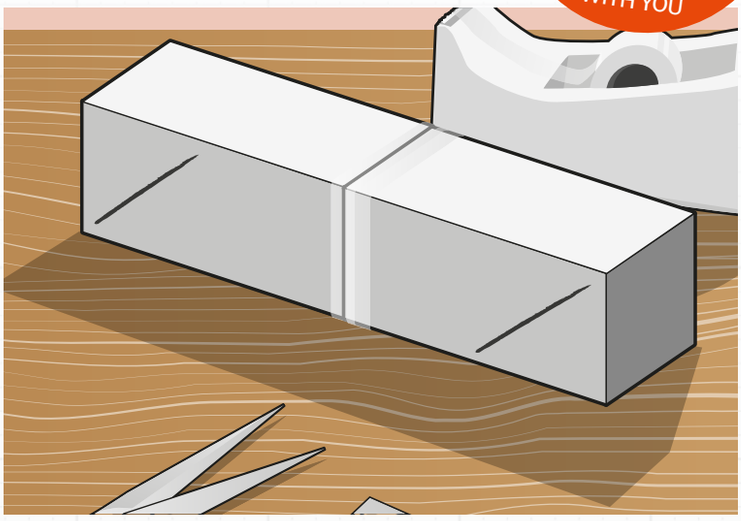
How to make a periscope

Look around corners and over walls with this awesome periscope you can make at home

DON'T DO IT ALONE
IF YOU'RE UNDER 18, MAKE SURE YOU HAVE AN ADULT WITH YOU



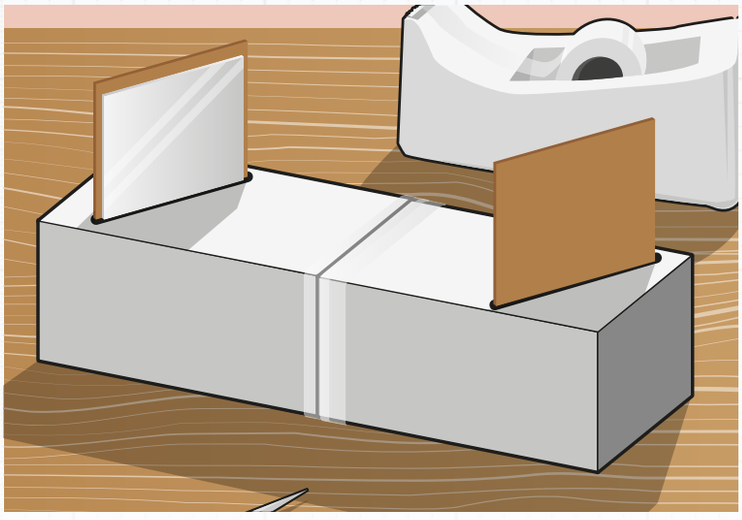


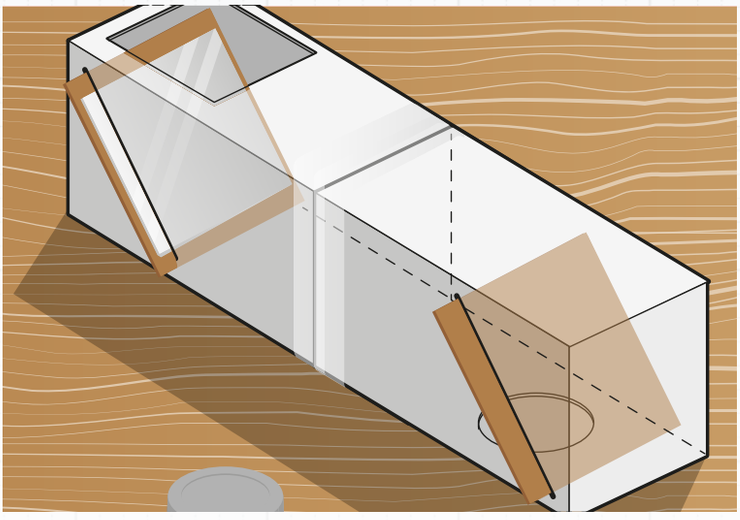
1 Create the tube

The first thing you will need to do is create a tube in which your mirrors will fit. Take two rectangular juice cartons and carefully cut the angled tops off them both with scissors. Cut four two-centimetre-long strips at the end of one carton, then slot the two cartons together with two of the flaps inside the other carton and two outside. Attach the two cartons together tightly with tape.

2 Cut the slots

Now you need to create slots for the mirrors. On the side of the carton at each end mark a 45-degree line. Make sure both lines are at the same angle, then turn over the carton and draw the same on the other side. You need to ensure that the lines are facing each other on both sides of the carton so the mirrors will slot in when you need them to.



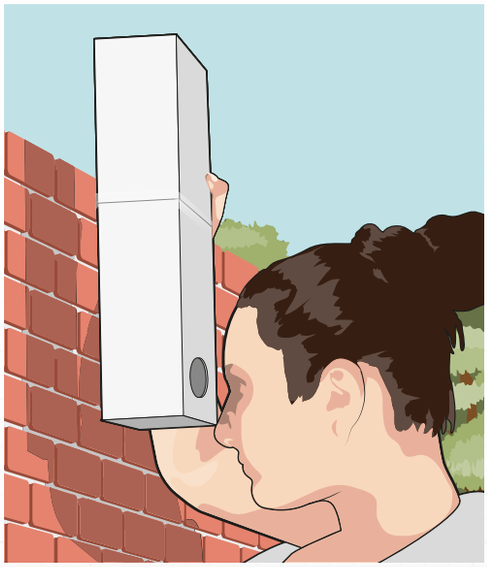


3 Add the mirrors

Cut out two eight-centimetre-square sections of thick card, then glue a six-centimetre mirror to the centre of each of these squares. While they dry, use your scissors to cut slots where you marked the 45-degree lines on the carton a moment ago. The mirrors stick out a little on the card, so you may need to cut a little extra out of the slit to make them fit properly.

4 Viewing holes

Once the mirrors are in, you can secure them in place with tape. Next, you'll need to cut out two holes in the box – one for your eye to look through and one so you can see the outside world. Draw around a bottle top and cut out the hole for your eyehole, then cut out a rectangle around five centimetres across and four centimetres high at the other end so you can see out of it.



5 Try it then tweak it

When you hold the eyehole up to your eye, you should be able to see through the hole at the other end of the periscope. Try looking over and around objects, over crowds or through doorways. You can also try making another periscope with one of the mirrors angled in a different direction if you want to see what's going on behind you.

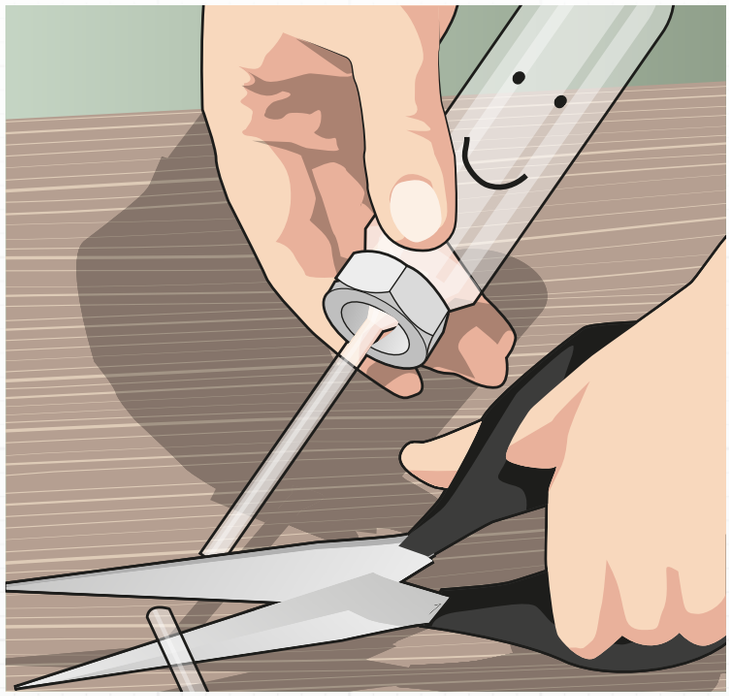
"Try looking over and around objects, over crowds or through doorways"

In summary...
When light hits the mirror, it is reflected straight down the tube of your periscope because the angle of the mirror is 45 degrees. The second mirror then reflects the same light into your eye. The angle is really important, so if you can't see out of your periscope you might need to check it's definitely aligned at exactly 45 degrees.

NEXT ISSUE
BUILD A MARBLE RUN
MAKE A CD RACER

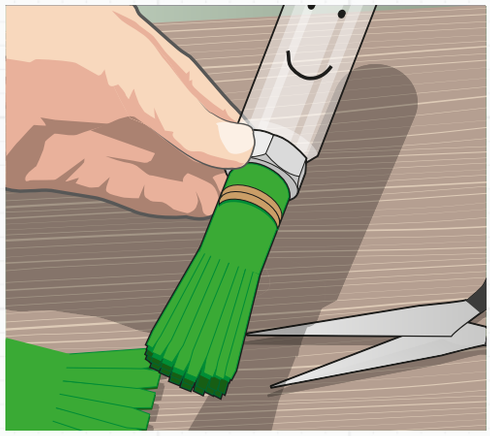
Build a Cartesian diver

Make a diver that rises and falls at your command



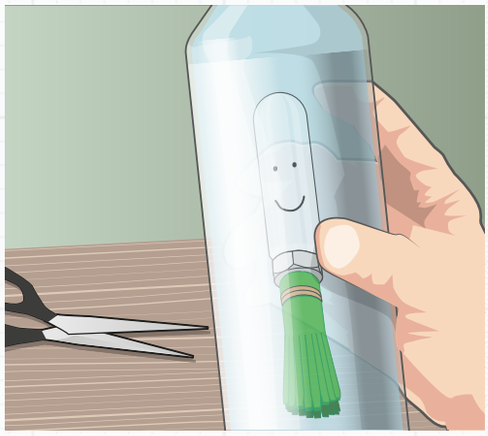
1 Prepare your pipette

For this experiment, you'll need a small, five-millilitre plastic pipette – the kind you might use in school science experiments. Slide a M10 nut onto the pipette, right up to the bulb at the top. Now cut the spout off the pipette so that the distance from the bulb to the cut is 8.5 centimetres. This will be the basis for your diver, so give him some personality. Draw a face onto the bulb using a permanent marker and add any other decorations you want.



2 Dress it up

Next you need to cut a dress-like soap out of a two-millimetre-thick foam craft sheet – you can see the shape above. First, cut a rectangle three centimetres wide and four centimetres tall, then cut out some flaps from one of the three-centimetre edges, rounding off the bottom of the flaps as you go. You should be left with a fan-like shape. Wrap this around the bottom of the pipette, right under the nut, and use a rubber band to attach it securely.



3 Dunk and test

You'll need a clear plastic bottle for this experiment – you can use a two-litre bottle if you have one, but a 500-millilitre one works just as well. Fill the bottle to the top with water, then push in the diver and screw on the lid. You'll see that the diver stays at the top, but squeeze the bottle tightly and you'll notice it starts to dive! Release it again and the diver will rise. You should also see the water level in the pipette increase when you squeeze the bottle.

In summary...
The diver is filled with air when you put it into the bottle, making it rise to the top. However, when you squeeze the bottle, the water is pushed into the pipette and the air is compressed. With the combined weight of this water in the pipette and the metal nut, the pipette sinks!

INBOX
Speak your mind...

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WIN!
AMAZING PRIZE FOR LETTER OF THE MONTH!
OPTICAL ILLUSIONS
Filled with a range of mind-boggling puzzles and experiments, discover the world of illusions that will leave you wondering HOW?!

Letter of the Month

Film fatigue

Dear **HIW**,
Here's a poser! I can listen to the same music again and again, spanning years, and still enjoy it, but I can only fully enjoy a movie once. Not so much the second time, provided there is a suitable interval, but that's it: a third time, no matter the interval, would be a bore. So, my question is, why the difference?
Ted Hirst


A report suggests that the average Briton listens to 3,500 songs a year

Well this question has really had us thinking Ted. The only scientific explanation to answer this lays in the principle of boredom itself. We feel bored as a result of a lack of sensory stimulation. In the case of watching a movie, the first time you see it the plot is revealed. Upon re-watching it a second or third time, the plot is no longer the focus so there may be a lack of cognitive stimulation. This isn't the case for everyone; many of us have favourite films we can watch time and time again. Our Senior Art Editor Duncan has watched *Jaws* well over 20 times! Music, however, doesn't require you to focus on a story or plot or last two to three hours like some films. It's a short burst of stimulation, often accompanied with another activity, such as listening to the top 40 while you go for a walk.

Evolution of languages

Hello **HIW**,
I really enjoy reading your magazine, but I have always wondered why there are different accents and languages?
Jessica Hartley

As a brief, simplified explanation for what is currently understood, this boils down to our ancestors' dispersal across the ages and the evolution of their communication, which developed from grunt signals to fully structured sentences. As they migrated around the globe, communication naturally developed in different ways and formed different languages. The introduction of accents with languages developed in a similar way. As groups that speak the same language separate geographically, becoming relatively isolated, their language continues to change to form accents.

Musical power drain

Dear **HIW**,
I am an avid reader of your magazine and really enjoy the varied and interesting articles. My question is, in a battery-powered audio device (ie radio), which genre of music (classical, heavy metal, jazz, folk etc) will run down the battery the fastest?
Daniel Stott

Great question Daniel, although we're afraid there isn't a definitive answer as to which music genres are the most power hungry. However, adjusting the equaliser settings to increase the bass of some genres of music has been found to affect power usage. There is also a link between the volume a song is played at and the amount of battery power drained, so it's mainly down to how loud you rock out.

What's happening on... social media?

This month, we asked: if you could hop on a spaceship tomorrow and be one of the first to colonise Mars, would you go and why?

"I would definitely go, would love to be an Earthling & a Martian but having a pacemaker will keep me on this planet. I know that my first snack would have to be a Mars bar & a packet of Space Invaders whilst listening to David Bowie - Life on Mars, all for obvious reasons"
@CGLo55op10

"Yes - I do like a challenge and if I could help to colonise Mars ready for the next generation who may need it in a hurry I would be proud to - a bit like donating blood - it is a gift but you will never know who will benefit from it - but someone will...and that is enough..."
@bexstarrh

"Oh, yes, I'd go! Imagine the sense of both seeing how incredibly insignificant we are [as Earth becomes a mere dot], but also how significant we are standing on another planet"
@catlittertray

"I definitely wouldn't, I like the familiarity of the Earth and those with me"
@bicyclegasoline

"No, we need to sort Earth out before we mess up another planet!"
@lisalittlespud

HOW IT WORKS

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Issue 111 on sale 19 April 2018

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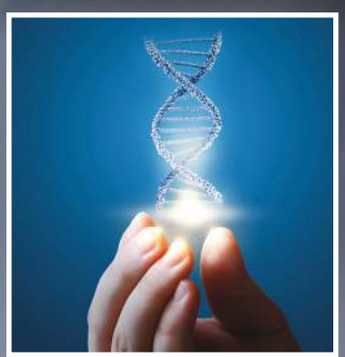

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AT THE CURRENT RATE OF DEMAND, GLOBAL OIL RESERVES ARE PREDICTED TO RUN OUT IN AROUND **50 YEARS**

40% OF THE POPULATION IN THE EU ARE EXPOSED TO ROAD TRAFFIC NOISE LEVELS OF OVER 55 DECIBELS

9 MONTHS

THE APPROXIMATE TIME TAKEN TO CONSTRUCT JOSEPH PAXTON'S CRYSTAL PALACE IN HYDE PARK

1 BILLION

THE NUMBER OF COLOURS THE IMAC PRO'S 5K RETINA DISPLAY CAN SUPPORT

THERE ARE CURRENTLY OVER

267,100

CLINICAL TRIALS IN OVER 200 COUNTRIES REGISTERED ON **CLINICALTRIALS.GOV**

BETWEEN 1950 AND 2009

900+

PEOPLE DIED ATTEMPTING SUMMIT CLIMBS IN THE HIMALAYAN MOUNTAINS

$167 MILLION

THE ESTIMATED COST OF THE PLANNED FLOATING ISLANDS PROJECT IN FRENCH POLYNESIA

201

THE WORLD-RECORD NUMBER OF BASE JUMPS PERFORMED IN 24 HOURS BY DAN SCHILLING IN 2006

15–25

THE AGES AT WHICH YOU ARE LIKELY TO EXPERIENCE DÉJÀ VU MOST OFTEN

6–8 MONTHS THE ESTIMATED TIME IT TAKES TO TRAVEL TO MARS WITH CURRENT TECHNOLOGIES

SPACEX'S FALCON HEAVY ROCKET CAN LIFT PAYLOADS OF NEARLY

64 TONS

7M

THE WORLD RECORD FOR THE HIGHEST SNOWBOARD AIR ON A SUPERPIPE, SET BY SHAUN WHITE IN 2010

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